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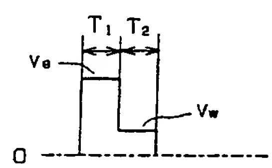
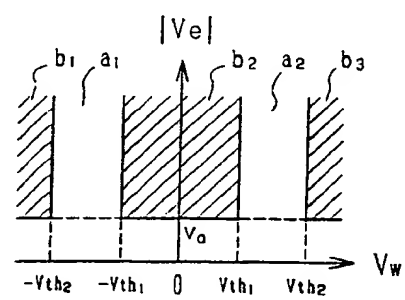
(54) **Liquid crystal display device having two metastable states and its driving method.**

(57) A liquid crystal display device containing chiral nematic a liquid crystal having a twisted structure is provided with a period during which a pulse voltage is applied that brings about a Frederick's transition and a period during which a voltage pulse, which is selected using the critical value that generates one of the two metastable states as a reference, is applied, and it displays by switching between the bistable states. Thereby a high speed multiplex-driven liquid crystal display device capable of performimg high precision display while maintaining high contrast and a wide viewing angle is achieved.



(a)



(b)

FIG. 29

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Field of the Invention

This invention relates to a liquid crystal display device that uses a chiral nematic liquid crystal, and more particularly it relates to a liquid crystal display device driven by a simple matrix driving by utilizing bistable switching and its driving method.

Description of the Prior Art

Currently, the liquid crystal display devices being used as display devices for office equipment, etc., use a twisted nematic (TN) liquid crystal or a supertwisted nematic (STN) liquid crystal. For example, these display systems, which are described by M. Schadt and W. Helfrich in *Appl. Phys. Lett.* 18 (1971) 127 or by T. J. Scheffer and J. Nehring in *Appl. Phys. Lett.* 45 (1984) 1021, do not have a memory effect, and therefore they are driven by a simple matrix driving method using voltage averaging or an active matrix driving method in which a transistor or other active element is provided at each picture element.

Other systems are being researched in addition to these, though they have not reached the application stage. For example, high speed technologies for voltage averaging are disclosed in JP-A-59-219720 and JP-A-60-196728, and systems that utilize bistable switching are disclosed in JP-B-1-51818, JP-B-3-26368 and JP-A-59-58420.

Problems the Invention is to Solve

However, the above prior art technologies have the following problems. When a twisted nematic liquid crystal is driven by voltage averaging, the ratio of the voltage V_{ON} for selecting the ON condition to the voltage V_{OFF} for selecting the OFF condition is given by the following equation where the number of scanning lines is N.

$$V_{ON}/V_{OFF} = ((N^{1/2} + 1)/(N^{1/2} - 1))^{1/2}$$

As can be seen from this equation, since V_{ON}/V_{OFF} approaches 1 as N becomes large, the contrast ratio falls. Considering the electrooptical characteristics and voltage waveforms of current liquid crystal devices, N is limited to approximately 500. Therefore, it is impossible to use this system to realize display devices for workstations, etc., requiring high precision displays. Also, the display characteristic is greatly dependent on the viewing angle, and the switching time from ON to OFF is long.

The technology disclosed in the aforementioned JP-A-60-196728 is aimed at shortening the above switching time. By this means, the switching from ON to OFF can be speeded up by giving the pretilt angle θ_1 on the lower substrate (angle formed between the director vector in contact with the liquid crystal alignment layer on the substrate and the substrate surface) and the pretilt angle θ_2 on the upper substrate opposite signs. Also, the technology disclosed in the aforementioned JP-A-59-219720 is aimed at stabilizing the operating condition by adding a chiral substance to the liquid crystal material. However, since the devices of the above mentioned documents do not have bistability and operate by a voltage averaging method, they are not suited to high precision display devices.

Prior art devices having bistability or plural stability states are suited to high precision display using many scanning lines when switching between the states can be performed selectively with a suitable voltage waveform, but each has its own inherent problems.

For example, since the device disclosed in JP-B-1-51818 (US-A-4,239,345) has bistability, information that has been written can be retained for a long period even without using active elements. However, since switching between the two stable states is basically performed by rapid cut off of the applied voltage and its gradual decline over approximately one second, this technology is not suited to simple matrix driving and its writing speed is extremely slow. Actually, JP-B-1-51818 (US-A-4,239,345) only describes the switching principle and does not disclose a method for simple matrix driving.

The technology disclosed in JP-A-59-58420 can select whether to write or not by controlling the applied voltage, but in order to clear the display, the liquid crystal layer must be heated until it takes on an isotropic phase. An extremely high voltage is required for writing.

Also, in an operating mode having bistability or plural stabilities, the stable state used for display is often not sufficiently stable with respect to energy, and therefore the orientation state of the liquid crystal in a condition in which the power to the device is cut off changes to the orientation state of the lowest energy. Particularly in cases in which the initial state such as that used in this invention and the orientation state used in display are different, when write scanning is performed on the initial orientation state at the time of power up, three orientation states exist together, though only for a short period, and degrade display quality.

The invention is intended to solve the above problems, and its purpose is to offer a high definition, high precision liquid crystal display device that can be driven by simple matrix driving.

Means for Solving the Problems

This object is achieved with a liquid crystal display device and its driving method as claimed.

Multiplex driving can be performed by using the voltage applied during the period the selected metastable state is maintained as a pulse lower than the threshold value in the two metastable states.

Assuming the directions of rubbing on the pair of transparent electrode substrates form an angle ϕ_r, the spiral pitch of the chiral nematic liquid crystal is adjusted by adding chiral material so that the twist angle in the initial state before voltage is applied is roughly ϕ_r.

Assuming the angles formed by the director vector in contact with the liquid crystal alignment layer on the substrates and the substrate surfaces are θ_1 and θ_2, respectively, in the initial state, θ_1 and θ_2 preferably have mutually opposite signs as shown in FIG. 1. That is, if the twist angle of the initial state of the chiral nematic liquid crystal is 180 degrees, then the above two director vectors are roughly parallel.

A chiral nematic liquid crystal having two metastable states different from its initial state as relaxation states means that assuming, for example, it has a twisted structure with a twist angle of 180 degrees in its initial state, it has a structure wherein one twist angle is 0 degree (uniform state) and the other twist angle is 360 degrees in its metastable states. Relaxation to one of the metastable states after Frederick's transition depends on the waveform of the applied pulse voltage, and both metastable states have the property of spontaneously relaxing to the initial state.

The twist angle ϕ in the initial state is not limited to 180 degrees and can be set to any desired angle. For example, a liquid crystal display device with a twist angle of 90 degrees in the initial state has a twisted structure wherein the twist angles in the metastable states are -90 degrees and 270 degrees, respectively, and it has been confirmed experimentally that switching between those metastable states is possible.

When the invention is applied to a liquid crystal display device that performs multiplex driving, the drive voltages are divided up into the voltage applied in the first period to generate Frederick's transition in the liquid crystal, the voltage applied in the following second period to select one of the two metastable states and the voltage applied in the third period, and all are voltage pulses. In the first period, a voltage pulse with a sufficiently large absolute value to bring about Frederick's transition can be applied, and the polarity of the voltage pulse can be changed in the first period. The voltage applied in the second period is selected using the critical value that generates one of the metastable states as a reference, namely the desired metastable state can be selected by a voltage pulse with a voltage exceeding the critical value and a voltage pulse not exceeding the critical value, respectively. When a voltage pulse whose absolute value is zero, i.e., no voltage, is applied to the liquid crystal element in the second period following the voltage pulse applied in the first period, one of the metastable states is formed, and if the absolute value of the applied voltage pulse exceeds zero but does not exceed the critical value, the same state is set. However, if a voltage pulse is applied in the second period whose absolute value exceeds the critical value, then it means the other metastable state is formed.

In the first period in which Frederick's transition is brought about, a voltage pulse with an absolute value greater than both the threshold value in the initial state and those in the two metastable states is applied. In the second period, which follows the first period, a voltage pulse is applied for selecting one or the other arrangements of the two metastable states for the liquid crystal molecule arrangement. A voltage pulse with the opposite polarity or same polarity as the polarity of the voltage pulse applied immediately before the second period, i.e., at the end of the first period, or with an absolute value of zero is selected for this voltage pulse.

When the twist angle of the liquid crystal molecules in the initial state is ϕ, the twist angles in the two metastable states generated as relaxation states after applying a pulse voltage group in the initial state are roughly (ϕ-180 degrees) and (ϕ + 180 degrees), and by applying a voltage pulse, whose absolute value exceeds the critical value and whose polarity is opposite that of the pulse applied at the end of the first period, immediately after establishing the first period in which the voltage pulse group that generates a Frederick's transition in the initial state and two metastable states is applied, an orientation state whose twist angle is roughly (ϕ-180 degrees) is selected, while applying a voltage pulse whose absolute value does not exceed the critical value and whose polarity is the same or whose absolute value is zero makes it possible to select an orientation state whose twist angle is roughly (ϕ + 180 degrees).

The third period is established immediately after the second period. The absolute value of the voltage pulse applied in the third period has a value lower than the threshold value existing between the two metastable states and maintains the selected metastable state.

Action

Below is an explanation of the relationship between Frederick's transition and the metastable state selected following it. FIG. 29 (a) shows an example of the waveform of the voltage pulse applied in the first period T_1 and the second period T_2. In the figure, the voltage of the voltage pulse applied in T_1 is V_e and the voltage of voltage pulse applied in T_2 is V_w. Their relationship is shown in (a) of the same figure, where $|V_e|$ is the vertical axis and V_w is the horizontal axis and the metastable states of a chiral nematic liquid crystal, which has a 180-degree twisted structure in its initial state, are shown in areas a_1, a_2, which show a metastable state of a twist angle of 0 degree, and in areas b_1, b_2, b_3 (hatched areas), which show a metastable state of a twist angle of 360 degrees. Notice that metastable states also exist in areas b_1, b_3. V_o is the voltage (reset voltage) required to bring about Frederick's transition, and V_{th1}, V_{th2} indicate the critical values for the state in a_1, a_2 and the state in b_1-b_3, respectively. When

$$|V_e| > V_o \text{ and } |V_{th1}| < |V_w| < |V_{th2}|$$

in (b) of the same figure, then the metastable states of a_1, a_2 are selected, and when

$$|V_e| > V_o \text{ and } |V_w| < |V_{th1}|$$

or

$$|V_e| > V_o \text{ and } |V_w| > |V_{th2}|$$

then it indicates that the metastable state of b_1-b_3 is selected. In the embodiments described below, the state of a_1 in the first to the sixth embodiments and the states of a_1 and a_2 in the seventh to the eleventh embodiments are selected as one metastable state, while the state of b_2 in the first to the tenth embodiments and the state of b_3 in the eleventh embodiment are selected as the other metastable state. Fig. 29 illustrates a case in which two critical values exist, but the existence of three or more critical values is possible.

In this invention, either metastable state can be created by selecting the effective voltage for the voltage pulse applied in the second period using the respective critical values of V_{th1}, V_{th2} above as a reference. Therefore, a case can be considered in which either area a_1 (a_2) or b_2 is selected using the above critical value $|V_{th1}|$ as a reference. Also, a case can be considered in which either area a_1 (a_2) or b_1 (b_3) is selected using $|V_{th2}|$ as a reference. That is, it is possible to select one of the metastable states in the second period by applying either a voltage that is higher than the critical value or a voltage that is lower than the critical value using the critical values that generate the two metastable states as a reference.

The switching principle of the liquid crystal display device of the invention is explained below. The bistable liquid crystal device disclosed in the aforementioned US-A-4,239,345 (D. W. Berreman) does not perform matrix driving, but it does explain the bistable state as follows. If a voltage sufficiently large enough to bring about Frederick's transition is applied, the liquid crystal molecules in the middle part of the liquid crystal layer (distance from lower substrate surface = liquid crystal layer thickness/2) stand at an angle of about 90 degrees with respect to the substrate surface (this state is referred to as the reset state). If the applied voltage is gradually lowered over about one second following this, then the liquid crystal molecules in the middle reverse the process of orientation change when the voltage was applied and relax to a state parallel with the substrate. The orientation state obtained in this manner is the uniform state. If the applied voltage is cut off suddenly, however, the liquid crystal molecules in the middle move in a direction opposite that when the voltage is gradually lowered due to the flow effect of the liquid crystal. D. W. Berreman referred to this phenomenon as backflow. Since the liquid crystal molecules in the middle continue to move in the opposite direction and lay down in a direction opposite that of the liquid crystal molecules near the substrate surface, they relax in a 360-degree twisted state. The selection of two bistable states is performed by this principle, but since the voltage must be lowered gradually over about one second to achieve relaxation in the uniform state, this technology had no practical application. That is, it was theoretically impossible to apply it to high speed switching by performing multiplex driving in a liquid crystal display device.

However, research by the present inventors revealed the following. That is, by applying a suitable voltage after resetting, backflow occurs and the liquid crystal molecules begin to relax to a 360-degree twisted state, but then the direction orientation change reverses and they begin to return to the original uniform state. If that voltage is larger than a certain value, then they continue to relax to the uniform state, but if it is smaller than a certain value, then their direction of orientation change reverses again and they relax to the 360-degree twisted state. The inventors discovered that this value exists as a critical value. This was confirmed by simulations as well as experimentally. The inventors arrived at the invention by taking advantage of this newly discovered phenomenon.

A liquid crystal electrooptical element of the invention operates as follows. After resetting, a pulse voltage is superposed on the applied bias

voltage. Though backflow definitely occurs after resetting, if the peak value or duration of the pulse voltage is greater than a certain value, then the direction of orientation change reverses and the original process is followed so that the liquid crystal molecules relax to the uniform state. If the peak value or duration of the pulse voltage is lower than a certain value, however, the liquid crystal molecules relax to a 360-degree twisted state according to the process described above. Since switching can be performed by adjusting the magnitude of the pulse voltage in this manner, extremely fast switching becomes possible, thus facilitating application to high precision displays. Of course, the liquid crystal electrooptical element of this invention and the liquid crystal electrooptical element disclosed by D. W. Berreman are completely different. The difference between the two is summed up in the operating principle described above.

The spectral characteristic of the invention is explained using the liquid crystal display device disclosed in the eighth embodiment described below. FIG. 30 shows the spectral characteristic when an ON condition is selected by switching. The wavelength is plotted on the horizontal axis while the transmittance is plotted on the vertical axis. The plot indicated by A in Fig. 30 is for the element used in this embodiment with a cell gap of 1.8 μm. A flat characteristic is obtained in a broad wavelength range of visible light, thus indicating good white display. The plot indicated by B in the same figure is the spectral characteristic when a cell gap of 20 μm is used and is provided for the sake of comparison. The presence of plural peaks indicates that display is colored. Therefore, the element used in this embodiment of the invention is superior with respect to the purity of display color.

Next, the dependency of transmittance on the viewing angle in the display element of the invention is shown in FIGS. 31 and 32. FIG. 31 shows the transmittance when ON (C in figure) and the transmittance when OFF (D in figure) when the viewing angle is inclined in the axial direction of the liquid crystal molecules at the interface from the substrate normal line. FIG. 32 shows similar plots when the viewing angle is changed in a direction perpendicular to that in FIG. 31. The change in transmittance when ON is small in the axial direction of the liquid crystal molecules and in the direction perpendicular to it (E in figure), and there is no inversion of display in a range of ±50 degrees. F in the figure indicates transmittance when OFF. The above viewing angle characteristic was obtained in this embodiment with a pretilt angle of about 5 degrees at the substrate interface, but for the sake of comparison, the characteristic for a pretilt angle of 45 degrees at the substrate interface is shown in FIGS. 33 and 34. In the figure, the plots indicated by G and I are when ON and the plots indicated by H and J are when OFF. The contrast ratio becomes 1 in a direction approximately 30 degrees from the substrate normal line in the axial direction of the liquid crystal molecules (FIG. 33). In a direction perpendicular to this, inversion of the display occurs at a position at approximately ±40 degrees (FIG. 34). Therefore, the effectiveness of the display element used in an embodiment of the invention can also be seen from the standpoint of the dependency of transmittance on the viewing angle.

Preferred embodiments of the invention will be explained in further detail below with reference to the drawings.

Brief Description of the Drawings

FIG. 1 is a cross section showing the structure of the liquid crystal display device of an embodiment.

FIG. 2 is a diagram showing the optical response corresponding to the driving waveforms of an embodiment.

FIG. 3 is a diagram showing the optical response corresponding to the driving waveforms of an embodiment.

FIG. 4 is a diagram of the circuit for driving the liquid crystal display device of an embodiment.

FIG. 5 is a diagram of the driving waveforms of an embodiment.

FIG. 6 is a diagram of the driving waveforms of an embodiment.

FIG. 7 is a diagram of the driving waveforms and the optical response of an embodiment.

FIG. 8 is an explanatory diagram of the timing of the applied voltage waveforms.

FIG. 9 is a diagram of the driving waveforms of an embodiment.

FIG. 10 is a diagram of the driving waveforms of an embodiment.

FIG. 11 is a diagram of the driving waveforms and the optical response of an embodiment.

FIG. 12 is an explanatory diagram of the timing of the applied voltage waveforms.

FIG. 13 is a diagram of the driving waveforms of an embodiment.

FIG. 14 is a diagram of the driving waveforms of an embodiment.

FIG. 15 is a diagram of the driving waveforms and the optical response

of an embodiment.

FIG. 16 is a diagram of the driving waveforms of an embodiment.

FIG. 17 is a diagram of the driving waveforms of an embodiment.

FIG. 18 is a diagram of the driving waveforms and the optical response of an embodiment.

FIG. 19 is an explanatory diagram of the timing of the applied voltage waveforms.

FIG. 20 is a diagram of the driving waveforms of an embodiment.

FIG. 21 is a diagram of the driving waveforms and the optical response of an embodiment.

FIG. 22 is an explanatory diagram of the timing of the applied voltage waveforms.

FIG. 23 is a diagram showing the temporal configuration of an embodiment.

FIG. 24 is a diagram of the driving waveforms of an embodiment.

FIG. 25 is an explanatory diagram of the timing of the applied voltage waveforms.

FIG. 26 is a diagram of the driving waveforms of an embodiment.

FIG. 27 is a diagram of the driving waveforms of an embodiment.

FIG. 28 is a diagram showing the electrode configuration of an embodiment.

FIG. 29 is a diagram showing the selection areas of the metastable states of the invention.

FIG. 30 is a graph showing the optical characteristic of an embodiment.

FIG. 31 is a graph showing the optical characteristic of an embodiment.

FIG. 32 is a graph showing the optical characteristic of an embodiment.

FIG. 33 is a graph showing the optical characteristic of an embodiment.

FIG. 34 is a graph showing the optical characteristic of an embodiment.

The invention is explained in detail below through specific embodiments. FIG. 1 is a cross section of the liquid crystal display device. In the figure, 1 are liquid crystal molecules, 2 is an alignment layer, 3 is an insulating film, 4 are transparent electrodes, 5 are glass substrates, 6 is a flattening layer, 7 are polarizing plates, 8 is a masking layer between picture elements, and θ_1 and θ_2 are the pretilt angles of the liquid crystal molecules at the interface. A cell fabricated by forming ITO transparent electrode patterns 4 and applying polyimide alignment layers 2 on glass substrates 5, rubbing the surface, and disposing the substrates opposite each other with the desired gap by means of suitable spacers was used.

First Embodiment

An optically active compound (E. Merck, Darmstadt, S811) was added to the liquid crystal material (Rodic K.K., Dn - 0.1), which demonstrates a nematic phase at room temperature, to adjust it to a helical pitch p of 3.2 μm. The cell comprised polyimide alignment layers rubbed in opposing parallel directions (180 degrees) on the upper and lower substrates separated by a gap d of 2.0 μm. When the above liquid crystal material was infused, the interface pretilt angles near the upper and lower substrates were approximately 4 degrees with opposite signs, and since $p/4 < d < 3p/4$, the orientation of the liquid crystal molecules took on a 180-degree twisted state with a helical axis in the normal direction of the substrate. The structure of a similar liquid crystal display element is outlined in FIG. 1. We sandwiched the sample obtained in this manner between two polarizing plates whose polarizations were roughly perpendicular to each other, applied the driving waveforms of the invention on the electrodes and evaluated the optical characteristic.

The driving waveforms of this embodiment are shown in FIG. 2. In the figure, 201 is the scanning electrode waveform, 202 is the signal electrode waveform, 203 is a composite waveform of 201 and 202, and 204 is the optical response when 203 is applied to the liquid crystal display element. Also, t_0 indicates the frame (scanning time for one screen) when OFF (i.e., dark state) is selected and t_1 and t_1' indicate the frames when ON (i.e., bright state) is selected. t_{01} and t_{11} correspond to selection periods, while t_{02}, t_{03} and t_{12}, t_{13} correspond to nonselection periods. At the end of the nonselection period, a period is established in which a voltage pulse such as $\pm(V_1 + V_2)$ in t_{03} and $\pm V_1$ in t_{13} and t_{13}' whose absolute value is greater than the threshold value of the element (i.e. the critical value for a Frederick's transition) is applied to bring about Frederick's transition. In OFF selection frame t_0, after the $\pm(V_1 + V_2)$ or $\pm V_1$ voltage pulse is applied immediately before selection period t_{01} and Frederick's transition is brought about, a pulse whose voltage absolute value is 0 is applied and the dark state selected in selection period t_{01}. In nonselection period t_{02}, a pulse whose voltage absolute value is lower than the threshold value of the element is applied, thus maintaining the dark state. In ON selection frame t_1, a pulse ($-V_2$) with a polarity opposite that of the pulse applied immediately before it is applied in selection period t_{11} and the bright state (metastable state different from that in the case of t_0) is selected. Since a pulse

whose voltage absolute value is lower than the threshold value of the element is applied in non-selection period t_{12}, the bright state is maintained. When the element was operated at 30°C and with V_1 = 34.0 V, V_2 = 1.7 V and pulse width P_w = 700 µs, the transmittance of the bright state was 44 percent (here and in the following the percentage of the transmittance is based on a transmittance of 100 percent when the two polarizing plates are disposed on the same optical system with their polarization axes parallel) and the contrast ratio between the two states was 65.

Second Embodiment

The driving waveforms applied to the liquid crystal display device in the second embodiment are shown in FIG. 3. In the figure, 301 is the scanning electrode waveform, 302 is the signal electrode waveform, 303 is a composite waveform of 301 and 302, and 304 is the optical response when 303 is applied to the liquid crystal display element. t_0 and t_0' indicate frames (scanning time for one screen) when OFF (i.e., dark state) is selected, and t_1 and t_1' indicate frames when ON (i.e., bright state) is selected. In t_0 and t_1, t_{01} and t_{11} correspond to selection periods and t_{02}, t_{03} and t_{12}, t_{13}correspond to nonselection periods. A period is established at the end of the nonselection periods in which voltage pulses such as V_1 - V_2 in t_{03} and -V_1 + V_2 in t_{13} whose absolute values are greater than the threshold value of the element are applied to bring about Frederick's transition. In OFF selection frame t_0, a pulse whose voltage absolute value is 0 is applied in selection period t_{01} and the dark state is selected after a voltage pulse (-V_1 in FIG. 3) whose absolute value is greater than the threshold value of the element is applied immediately before selection period t_{01} to bring about Frederick's transition. In nonselection period t_{02}, a pulse whose voltage absolute value is lower than the threshold value of the element is applied, thus maintaining the dark state. During ON selection frame t_1, a pulse (-V_2) whose polarity is opposite that of the pulse applied immediately before it is applied in selection period t_{11} and the bright state is selected. In nonselection period t_{12}, a pulse whose voltage absolute value is lower than the threshold value of the element is applied thus maintaining the bright state. When an element same as in the first embodiment was operated at 30°C and with V_1 = 36.0 V, V_2 = 1.8 V and pulse width P_w = 1.0 ms, the transmittance of the bright state was 44 percent and the contrast ratio between the two states was 68. Also, the polarity of the applied waveform is inverted in two temporally adjacent frames in this embodiment, thereby avoiding an excessive DC component to be applied to the element.

Third Embodiment

An optically active compound (E. Merck, Darmstadt, S811) was added to the liquid crystal material (E. Merck, Darmstadt, ZLI-1557), which demonstrates a nematic phase at room temperature, to adjust it to a helical pitch p of 3.5 µm. The cell comprised polyimide alignment layers disposed on a scanning electrode group and signal electrode group formed from ITO and rubbed in opposing parallel directions (180 degrees) on the upper and lower substrates separated by a gap d of 1.8 µm. When the above liquid crystal material was infused, the interface pretilt angles near the upper and lower substrates were approximately 4 degrees with opposite signs, and since $p/4 < d < 3p/4$, the orientation of the liquid crystal molecules took on a 180-degree twisted state with a helical axis in the normal direction of the substrate. The structure of the liquid crystal display element is the same as that outlined in FIG. 1. The element of this configuration generates two metastable states with roughly a 0-degree twisted (uniform) state and roughly a 360-degree twisted state depending on the applied driving waveforms. We sandwiched the liquid crystal panel obtained in this manner between two polarizing plates and fabricated a liquid crystal display device using the circuit configuration shown in FIG. 4 to confirm the effectiveness of the invention. In the figure, 11 is the liquid crystal panel, 12 is a backlight used as the illumination means, 13 is the drive circuit (shift registers, logic circuit) for applying voltage to the scanning electrode group of liquid crystal panel 11, 14 is the drive circuit (shift registers, latches, logic circuit) for applying voltage to the signal electrode group, 15 is a reference signal generation circuit, and 16 is a line-sequential scanning circuit (ROM, controller).

The driving waveforms of this embodiment are shown in FIG. 5. In the figure, 201 is the scanning electrode waveform, 202 is the signal electrode waveform, and 203 is a composite waveform of 201 and 202. t_0 and t_1 indicate frames (scanning time for one screen) in which a 360-degree twisted state (i.e., OFF) and a uniform state (i.e., ON) are selected, respectively. t_{01} and t_{11} correspond to selection periods, while t_{02}, t_{03} and t_{12}, t_{13} correspond to nonselection periods. At the end of the nonselection periods, a period is established in which a voltage pulse such as $\pm(V_1 - V_3)$ in t_{03} and $\pm(V_1 + V_3)$ in t_{13} whose absolute value is greater than the threshold value of the element is applied to bring about Frederick's transition. In OFF selection frame t_0, after a voltage pulse (not shown) whose absolute value is greater than the threshold value of the element is applied immediately before

selection period t_{01} and Frederick's transition is brought about, a pulse with the same polarity and whose voltage absolute value is $|V_3 - V_2|$ is applied and the OFF state selected in selection period t_{01}. In nonselection period t_{02}, a pulse whose voltage absolute value is lower than the threshold value of the element is applied, thus maintaining the same state. In ON selection frame t_1, a pulse $(-V_2 - V_3)$ with a polarity opposite that of the pulse applied immediately before it is applied in selection period t_{11} and the ON state is selected. Since a pulse whose voltage absolute value is lower than the threshold value of the element is applied in nonselection period t_{12}, the same state is maintained. When the element was operated at 30°C and with V_1 = 30.0 V, V_2 = 1.0 V, V_3 = 1.5 V, pulse width P_w = 250 μs, and a duty ratio of 1/400 ($t_{01} = t_{11}$ = 500 μs, $t_0 = t_1$ = 400 x 500 μs), selective switching of the element described above was possible.

Fourth Embodiment

Other driving waveforms applied in the liquid crystal display device of the third embodiment are shown in FIG. 6. In the figure, 301 is the scanning electrode waveform, 302 is the signal electrode waveform and 303 is a composite waveform of 301 and 302. t_0 and t_1 indicate frames (scanning time for one screen) in which a 360-degree twisted state (i.e., OFF) and the uniform state (i.e., ON) are selected, respectively. t_{01} and t_{11} correspond to selection periods, and t_{02}, t_{03} and t_{12}, t_{13} correspond to nonselection periods. At the end of the nonselection periods, a period is established in which a voltage pulse such as $\pm(V_1 - V_2)$ in t_{03} and $\pm(V_1 \pm V_2)$ in t_{13} whose absolute value is greater than the threshold value of the element is applied to bring about Frederick's transition. In OFF selection frame t_0, after a voltage pulse (not shown) whose absolute value is greater than the threshold value of the element is applied immediately before selection period t_{01} and Frederick's transition is brought about, a pulse with the same polarity and whose voltage absolute value is 0 is applied and the OFF state selected in selection period t_{01}. In nonselection period t_{02}, a pulse whose voltage absolute value is lower than the threshold value of the element is applied, thus maintaining the same state. In ON selection frame t_1, a pulse $(-V_2)$ with a polarity opposite that of the pulse applied immediately before it is applied in selection period t_{11} and the ON state is selected. Since a pulse whose voltage absolute value is lower than the threshold value of the element is applied in nonselection period t_{12}, the same state is maintained. The driving waveforms of this embodiment are equivalent to those in the third embodiment where $V_2 = V_3$.

When the element was operated at 30°C and with V_1 = 30.0 V, V_2 = 1.0 V, V_3 = 1.0 V, pulse width P_w = 250 μs, and a duty ratio of 1/400 ($t_{01} = t_{11}$ = 500 μs, $t_0 = t_1$ = 400 x 500 μs), selective switching of the element described above was possible. The optical response corresponding to the driving waveforms when operated with polarizing plates, where a 360-degree twisted state is the dark state and the uniform state is the bright (light transmission) state, is shown in FIG. 7. In the figure, F_1 and F_4 indicate OFF selection frames, F_2 and F_3 indicate ON selection frames, and T_1, T_2, T_3 and T_4 are each selection periods. The light transmittance in the bright state with this optical arrangement was 72 percent, and the contrast ratio between the two states was 68.

FIG. 8 shows the timing of waveforms applied to selected adjacent scanning electrodes when the driving waveforms of the third embodiment and this embodiment are applied to a matrix comprising plural electrodes and line-sequential scanning is performed.

Fifth Embodiment

FIG. 9 shows other driving waveforms applied in the liquid crystal display device of the third embodiment. In the figure, 601 is the scanning electrode waveform, 602 is the signal electrode waveform and 603 is a composite waveform of 601 and 602. t_0 and t_1 indicate frames (scanning time for one screen) in which a uniform state (i.e., ON) and a 360-degree twisted state (i.e., OFF) are selected, respectively. t_{01} and t_{11} correspond to selection periods, and t_{02}, t_{03} and t_{12}, t_{13} correspond to nonselection periods. At the end of the nonselection period, a period is established in which a voltage pulse such as $\pm(V_1 + V_3)$ in t_{03} and $\pm(V_1 - V_3)$ in t_{13} whose absolute value is greater than the threshold value of the element is applied to bring about Frederick's transition. In ON selection frame t_0, after a voltage pulse (not shown) whose absolute value is greater than the threshold value of the element is applied immediately before selection period t_{01} and Frederick's transition is brought about, a pulse with opposite polarity and whose voltage absolute value is $|V_3 + V_2|$ is applied and the ON state selected in selection period t_{01}. In nonselection period t_{02}, a pulse whose voltage absolute value is lower than the threshold value of the element is applied, thus maintaining the same state. In OFF selection frame t_1, a pulse $(-V_3 + V_2)$ with the same polarity as that of the pulse applied immediately before it is applied in selection period t_{11} and the OFF state is selected. Since a pulse whose voltage absolute value is lower than the threshold value of the element is applied in nonselection period t_{12}, the same state is maintained.

When the element was operated at 30 °C and with V_1 = 30.0 V, V_2 = 1.0 V, V_3 = 1.5 V, pulse width P_w = 400 μs, and a duty ratio of 1/400 (t_{01} = t_{11} = 400 μs, t_0 = t_1 = 400 x 400 μs), selective switching of the element described above was possible. Also, the polarity of the applied waveform is inverted in two temporally adjacent frames in this embodiment, thereby avoiding an excessive DC component to be applied to the element.

Sixth Embodiment

FIG. 10 shows other driving waveforms applied in the liquid crystal display device of the third embodiment. In the figure, 701 is the scanning electrode waveform, 702 is the signal electrode waveform and 703 is a composite waveform of 701 and 702. t_0 and t_1 indicate frames (scanning time for one screen) in which a uniform state (i.e., ON) and a 360-degree twisted state (i.e., OFF) are selected, respectively. t_{01} and t_{11} correspond to selection periods, and t_{02}, t_{03} and t_{12}, t_{13} correspond to nonselection periods. At the end of the nonselection periods, a period is established in which a voltage pulse such as $\pm(V_1 + V_2)$ in t_{03} and $\pm(V_1 - V_2)$ in t_{13} whose absolute value is greater than the threshold value of the element is applied to bring about Frederick's transition. In ON selection frame t_0, after a voltage pulse (not shown) whose absolute value is greater than the threshold value of the element is applied immediately before selection period t_{01} and Frederick's transition is brought about, a voltage pulse ($-2V_2$) with a polarity opposite that of the pulse applied immediately before it is applied and the ON state selected in selection period t_{01}. In nonselection period t_{02}, a pulse whose voltage absolute value is lower than the threshold value of the element is applied, thus maintaining the same state. In OFF selection frame t_1, a pulse whose voltage absolute value is 0 is applied in selection period t_{11} and the ON state is selected. Since a pulse whose voltage absolute value is lower than the threshold value of the element is applied in nonselection period t_{12}, the same state is maintained. The driving waveforms of this embodiment are equivalent to those in the third embodiment where V_2 = V_3. When the element was operated at 30 °C and with V_1 = 30.0 V, V_2 = 1.0 V, pulse width P_w = 400 μs, and a duty ratio of 1/400 (t_{01} = t_{11} = 400 μs, t_0 = t_1 = 400 x 400 μs), selective switching of the element described above was possible. The optical response corresponding to the driving waveforms when operated with polarizing plates, where a 360-degree twisted state is the dark state and the uniform state is the bright (light transmission) state, is shown in FIG. 11. In the figure, F_1 and F_4 indicate OFF selection frames, F_2 and F_3 indicate ON selection frames, and T_1, T_2, T_3 and T_4 are each selection periods. The light transmittance in the bright state with this optical arrangement was 75 percent, and the contrast ratio between the two states was 66. FIG. 12 shows the timing of waveforms applied to selected adjacent scanning electrodes when the driving waveforms of the fifth embodiment and this embodiment are applied to a matrix comprising plural electrodes and line-sequential scanning is performed. Also, the polarity of the applied waveform is inverted in two temporally adjacent frames in this embodiment, thereby avoiding an excessive DC component to be applied to the element.

Seventh Embodiment

An optically active compound (E. Merck, Darmstadt, S811) was added to the liquid crystal material (E. Merck, Darmstadt, ZLI-1557), which demonstrates a nematic phase at room temperature, to adjust it to a helical pitch p of 3.5 μm. The cell comprised polyimide alignment layers disposed on a scanning electrode group and signal electrode group formed from ITO and rubbed in opposing parallel directions (180 degrees) on the upper and lower substrates separated by a gap d of 1.8 μm. When the above liquid crystal material was infused, the interface pretilt angles near the upper and lower substrates were approximately 5 degrees with opposite signs, and since $p/4 < d < 3p/4$, the orientation of the liquid crystal molecules took on a 180-degree twisted state with a helical axis in the normal direction of the substrate. The structure of the liquid crystal display element is similar to that outlined in FIG. 1. The element of this configuration generates two metastable states with roughly a 0-degree twisted (uniform) state and roughly a 360-degree twisted state depending on the applied driving waveforms. We sandwiched the liquid crystal panel obtained in this manner between two polarizing plates and fabricated a liquid crystal display device using the circuit configuration shown in FIG. 4 to confirm the effectiveness of the invention. In the explanation below, the threshold voltages for bringing about Frederick's transition in the initial state (180-degree twist), approximately 0-degree twisted (uniform) state and approximately 360-degree twisted state are indicated by $V_{th}(180)$, $V_{th}(0)$ and $V_{th}(360)$, respectively, and these are collectively referred to as V_{th}. Also, the voltage critical value when selecting one of the two metastable states according to the magnitude of the root-mean-square value of the voltage pulse group applied immediately after bringing about Frederick's transition is indicated by V_c.

The driving waveforms of this embodiment are shown in FIG. 13. In the figure, 201 is the scanning electrode waveform, 202 is the signal electrode

waveform, and 203 is a composite waveform of 201 and 202. t_0 and t_1 indicate frames (scanning time for one screen) in which a 360-degree twisted state (i.e., OFF) and uniform state (i.e., ON) are selected, respectively. t_{01} and t_{11} correspond to selection periods, while t_{02}, t_{03} and t_{12}, t_{13} correspond to nonselection periods. At the end of the nonselection period, a period is established in which a voltage pulse such as $\pm(V_1 + V_3)$ in t_{03} and $\pm(V_1 - V_3)$ in t_{13} whose absolute value is greater than V_{th} is applied to bring about Frederick's transition. In OFF selection frame t_0, after a voltage pulse (not shown) whose absolute value is greater than V_{th} is applied immediately before selection period t_{01} and Frederick's transition is brought about, a pulse $\pm(V_2 - V_3)$ whose voltage absolute value is less than V_c is applied and the OFF state selected in selection period t_{01}. In nonselection period t_{02}, a pulse $\pm V_3$ whose voltage absolute value is less than $V_{th}(0)$ and $V_{th}(360)$ is applied, thus maintaining the same state. In ON selection frame t_1, a pulse $\pm(V_2 - V_3)$ whose absolute value is greater than V_c is applied in selection period t_{11} and the ON state is selected. Since a pulse $\pm V_3$ whose voltage absolute value is less than $V_{th}(0)$ and $V_{th}(360)$ is applied in nonselection period t_{12}, the same state is maintained. When the element was operated at 30°C and with V_1 = 30.0 V, V_2 = 1.5 V, V_3 = 1.0 V, pulse width P_w = 250 µs, and a duty ratio of 1/400 ($t_{01} = t_{11}$ = 500 µs, $t_0 = t_1$ = 400 x 500 µs), selective switching of the element described above was possible.

Eighth Embodiment

Other driving waveforms applied in the liquid crystal display device of the seventh embodiment are shown in FIG. 14. In the figure, 301 is the scanning electrode waveform, 302 is the signal electrode waveform and 303 is a composite waveform of 301 and 302. t_0 and t_1 indicate frames (scanning time for one screen) in which a 360-degree twisted state (i.e., OFF) and uniform state (i.e., ON) are selected, respectively. t_{01} and t_{11} correspond to selection periods, and t_{02}, t_{03} and t_{12}, t_{13} correspond to nonselection periods. At the end of the nonselection periods, a period is established in which a voltage pulse such as $\pm(V_1 \pm V_2)$ in t_{03} and t_{13} whose absolute value is greater than V_{th} is applied to bring about Frederick's transition. In OFF selection frame t_0, after a voltage pulse (not shown) whose absolute value is greater than V_{th} is applied immediately before selection period t_{01} and Frederick's transition is brought about, a pulse whose voltage absolute value is 0 ($\leq V_c$) is applied and the OFF state selected in selection period t_{01}. In nonselection period t_{02}, a pulse $\pm V_2$ whose voltage absolute value is less than $V_{th}(0)$ and $V_{th}(360)$ is applied, thus maintaining the same state. In ON selection frame t_1, a pulse $\pm 2V_2$ with an absolute value greater than V_c is applied in selection period t_{11} and the ON state is selected. Since a pulse $\pm V_2$ whose voltage absolute value is less than $V_{th}(0)$ and $V_{th}(360)$ is applied in nonselection period t_{12}, the same state is maintained. The driving waveforms of this embodiment are equivalent to those in the seventh embodiment where $V_2 = V_3$.

When the element was operated at 30°C and with V_1 = 30.0 V, V_2 = 1.0 V, pulse width P_w = 250 µs, and a duty ratio of 1/400 ($t_{01} = t_{11}$ = 500 µs, $t_0 = t_1$ = 400 x 500 µs), selective switching of the element described above was possible. The optical response corresponding to the driving waveforms when operated with polarizing plates, where a 360-degree twisted state is the dark state and the uniform state is the bright (light transmission) state, is shown in FIG. 15. In the figure, F_1 and F_4 indicate OFF selection frames, F_2 and F_3 indicate ON selection frames, and T_1, T_2, T_3 and T_4 are each selection periods. The light transmittance in the bright state with this optical arrangement was 72 percent, and the contrast ratio between the two states was 88.

FIG. 8 shows the timing of waveforms applied to selected adjacent scanning electrodes when the driving waveforms of the seventh embodiment and this embodiment are applied to a matrix comprising plural electrodes and line-sequential scanning is performed.

Ninth Embodiment

FIG. 16 shows other driving waveforms applied in the liquid crystal display device of the seventh embodiment. In the figure, 601 is the scanning electrode waveform, 602 is the signal electrode waveform and 603 is a composite waveform of 601 and 602. t_0 and t_1 indicate frames (scanning time for one screen) in which a uniform state (i.e., ON) and a 360-degree twisted state (i.e., OFF) are selected, respectively. t_{01} and t_{11} correspond to selection periods, and t_{02}, t_{03} and t_{12}, t_{13} correspond to nonselection periods. At the end of the nonselection period, a period is established in which a voltage pulse such as $\pm V_1$ in t_{03} and $\pm(V_1 - V_2)$ in t_{13} whose absolute value is greater than the threshold value of the element is applied to bring about Frederick's transition. In ON selection frame t_0, after a voltage pulse (not shown) whose absolute value is greater than V_{th} is applied immediately before selection period t_{01} and Frederick's transition is brought about, a pulse $\pm V_2$ whose voltage absolute value is greater than V_c is applied and the ON state selected in selection period t_{01}. In nonselection period t_{02}, a pulse $\pm V_2$ whose voltage absolute value is less than $V_{th}(0)$ and $V_{th}(360)$ is

applied, thus maintaining the same state. In OFF selection frame t_1, a pulse whose absolute value is 0 ($\leq V_c$) is applied in selection period t_{11} and the OFF state is selected. Since a pulse $\pm V_2$ or 0 whose voltage absolute value is less than $V_{th}(0)$ and $V_{th}(360)$ is applied in nonselection period t_{12}, the same state is maintained. When the element was operated at 30°C and with V_1 = 30.0 V, V_2 = 2.0 V, pulse width P_w = 200 µs, and a duty ratio of 1/400 (t_{01} = t_{11} = 400 µs, t_0 = t_1 = 400 x 400 µs), selective switching of the element described above was possible.

Tenth Embodiment

FIG. 17 shows other driving waveforms applied in the liquid crystal display device of the seventh embodiment. In the figure, 701 is the scanning electrode waveform, 702 is the signal electrode waveform and 703 is a composite waveform of 701 and 702. t_0 and t_1 indicate frames (scanning time for one screen) in which a uniform state (i.e., ON) and a 360-degree twisted state (i.e., OFF) are selected, respectively. t_{01} and t_{11} correspond to selection periods, and t_{02}, t_{03} and t_{12}, t_{13} correspond to nonselection periods. At the end of the nonselection period, a period is established in which a voltage pulse such as $\pm(V_1 - V_2)$ in t_{03} and $\pm(V_1 - V_3)$ in t_{13} whose absolute value is greater than V_{th} is applied to bring about Frederick's transition. In ON selection frame t_0, after a voltage pulse (not shown) whose absolute value is greater than V_{th} is applied immediately before selection period t_{01} and Frederick's transition is brought about, a voltage pulse $\pm V_2$ whose absolute value is greater than V_c is applied and the ON state selected in selection period t_{01}. In nonselection period t_{02}, a pulse $\pm V_2$ or $\pm V_3$ whose voltage absolute value is lower than $V_{th}(0)$ and $V_{th}(360)$ is applied, thus maintaining the same state. In OFF selection frame t_1, a pulse whose voltage absolute value is less than V_c is applied in selection period t_{11} and the OFF state is selected. Since a pulse $\pm V_2$ or $\pm V_3$ whose voltage absolute value is lower than $V_{th}(0)$ and $V_{th}(360)$ is applied in nonselection period t_{12}, the same state is maintained. When the element was operated at 30°C and with V_1 = 30.0 V, V_2 = 2.0 V, V_3 = 0.5 V, pulse width P_w = 200 µs, and a duty ratio of 1/400 (t_{01} = t_{11} = 400 µs, t_0 = t_1 = 400 x 400 µs), selective switching of the element described above was possible. The optical response corresponding to the driving waveforms when operated with polarizing plates, where a 360-degree twisted state is the dark state and the uniform state is the bright (light transmission) state, is shown in FIG. 18. In the figure, F_1 and F_4 indicate OFF selection frames, F_2 and F_3 indicate ON selection frames, and T_1, T_2, T_3 and T_4 are each selection periods. The light transmittance in the bright state with this optical arrangement was 75 percent, and the contrast ratio between the two states was 66.

FIG. 19 shows the timing of waveforms applied to selected adjacent scanning electrodes when the driving waveforms of the ninth embodiment and this embodiment are applied to a matrix comprising plural electrodes and line-sequential scanning is performed.

Eleventh Embodiment

Where the voltage critical values are V_{c1} and V_{c2} when one or the other of the two metastable states is selected depending on the magnitude of the root-mean-square value of the voltage pulse group applied immediately after bringing about Frederick's transition, then the metastable state generated is roughly 360-degree twisted state when $0 \leq V_r < V_{c1}$ roughly 0-degree twisted (uniform) state when $V_{c1} \leq V_r < V_{c2}$ roughly 360-degree twisted state when $V_{c2} \leq V_r$.

Other driving waveforms applied in the liquid crystal display device of the seventh embodiment are shown in FIG. 20. In the figure, 201 is the scanning electrode waveform, 202 is the signal electrode waveform and 203 is a composite waveform of 201 and 202. t_0 and t_1 indicate frames (scanning time for one screen) in which a 360-degree twisted state (i.e., OFF) and the uniform state (i.e., ON) are selected, respectively. t_{01} and t_{11} correspond to selection periods, and t_{02} and t_{12} correspond to nonselection periods. At the end of the nonselection period and in the first half of the selection period, a period is established in which a voltage pulse whose absolute value, which becomes $\pm(V_1 \pm V_3)$ depending on the superposed signal waveform, is greater than V_{th} is applied to bring about Frederick's transition. In OFF selection frame t_0, after a voltage pulse $(-V_1 - V_3)$ whose absolute value is greater than V_{th} is applied in the first half of selection period t_{01} and Frederick's transition is brought about, a pulse $(V_2 + V_3)$ whose voltage absolute value is greater than V_{c2} is applied and the OFF state selected in the last half of the period. In nonselection period t_{02}, a pulse $(\pm V_3)$ whose voltage absolute value is less than $V_{th}(0)$ and $V_{th}(360)$ is applied, thus maintaining the same state. In ON selection frame t_1, a voltage pulse $(-V_1 + V_3)$ whose absolute value is greater than V_{th} is applied in the first half of selection period t_{11} and Frederick's transition is brought about, after which a pulse $(V_2 - V_3)$ whose absolute value is greater than or equal to V_{c1} and less than V_{c2} is applied in the last half of the period and the ON state is selected. Since a pulse $\pm V_3$ whose voltage absolute value is less than $V_{th}(0)$ and $V_{th}(360)$ is applied in nonselection period t_{12}, the

same state is maintained. When the element was operated at 30°C and with V_1 = 30.0 V, V_2 = 12.0 V, V_3 = 2.0 V, pulse width P_w = 250 μs, and a duty ratio of 1/400 (t_{01} = t_{11} = 500 μs, t_0 = t_1 = 400 x 500 μs), selective switching of the element described above was possible. The optical response corresponding to the driving waveforms when operated with polarizing plates, where a 360-degree twisted state is the dark state and the uniform state is the bright (light transmission) state, is shown in FIG. 21. In the figure, F_1 and F_4 indicate OFF selection frames, F_2 and F_3 indicate ON selection frames, and T_1, T_2, T_3 and T_4 are each selection periods. The light transmittance in the bright state with this optical arrangement was 72 percent, and the contrast ratio between the two states was 88.

FIG. 22 shows the timing of waveforms applied to selected adjacent scanning electrodes when the driving waveforms of this embodiment are applied to a matrix comprising plural electrodes and line-sequential scanning is performed.

Twelfth Embodiment

An optically active compound (E. Merck, Darmstadt, S811) was added to a liquid crystal material (E. Merck, Darmstadt, MJ90179) available on the market to adjust it to a helical pitch p of 3.6 μm. The cell comprised polyimide alignment layers disposed on a scanning electrode group and signal electrode group formed from ITO and rubbed in opposing parallel directions (180 degrees) on the upper and lower substrates separated by a gap d of 2.0 μm. When the above liquid crystal material was infused, the interface pretilt angles near the upper and lower substrates were approximately 4 degrees with opposite signs, and since $p/4 < d < 3p/4$, the orientation of the liquid crystal molecules took on a 180-degree twisted state with a helical axis in the normal direction of the substrate. The structure of the liquid crystal display element is similar to that outlined in FIG. 1. The element of this configuration generates two metastable states with roughly a 0-degree twisted (uniform) state and roughly a 360-degree twisted state depending on the applied driving waveforms. We used the liquid crystal panel obtained in this manner to fabricate a liquid crystal display device with the circuit configuration shown in FIG. 4 in order to confirm the effectiveness of the invention.

A basic outline of this embodiment is shown in FIG. 23, wherein time is plotted on the horizontal axis T, 21 indicates powering ON of the power source, 22 indicates the duration the reset pulse is applied, 23 indicates the start of write scanning, and 24 indicates powering ON of the illumination means. Assuming a liquid crystal display element member with two metastable states which differ from the initial orientation state and that switches between those two metastable states, a configuration is employed with a reset pulse period in which a voltage waveform for switching the initial orientation state to one of the two metastable states after powering ON 21 is applied and that begins actual write scanning 23 by display data when the illumination means is switched ON 24. If the liquid crystal display element is a reflective type and does not require an illumination means, the item regarding switching ON of the illumination means may, of course, be omitted.

FIG. 24 shows an example of the driving waveforms applied to the liquid crystal layer during reset pulse period 22. In the figure, T_1 is a period during which a pulse whose voltage absolute value is greater than the threshold value is applied to bring about Frederick's transition in the liquid crystal, and T_2 is a period during which a pulse whose polarity is the opposite (201) or the same (202) with respect to the last pulse of T_1 or whose absolute value is zero (203) is applied for selecting one or the other of the metastable states. The waveform of 201 generates a metastable state with a twist angle of roughly (ϕ-180 degrees) with respect to the twist angle ϕ of the initial state, and the waveforms of 202 and 203 generate a metastable state with a twist angle of roughly (ϕ+180 degrees). When a voltage of ±30 V was applied in T_1 with a pulse duration of 500 μs and was applied to the liquid crystal display device described above, a uniform orientation was obtained with the waveform of 201 which applied a voltage of -1.5 V in T_2, and an orientation with roughly a 360-degree twist was obtained with the waveform of 202 and 203 which applied a voltage of +1.5 V in T_2.

Thirteenth Embodiment

Using the driving waveform of the twelfth embodiment, an example is described that yields a similar effect by line-sequential scanning. FIG. 25 shows the timing when a driving waveform is applied to (2k + 1) adjacent scanning electrodes whose center is the nth electrode by shifting the phase every k number of scanning electrodes. In the figure, the phase difference is equivalent to two pulses using the waveform of 203 in FIG. 24, but the waveform of 201 and 202 in FIG. 24 can be used, or the phase difference may be set as desired. Assuming k = 1, then line-sequential scanning is performed on every other scanning electrode, and if k ≧ 2, then scanning is performed in blocks. As in the twelfth embodiment, the waveform of 201 generates a metastable state with a twist angle of roughly (ϕ-180 degrees) with respect to the twist angle ϕ of the initial state, and the

waveform of 202 and 203 generates a metastable state with a twist angle of roughly (ϕ + 180 degrees). When the liquid crystal display device described above was applied using the voltage and pulse duration conditions of the twelfth embodiment and with k = 1, a uniform orientation was obtained with the waveform of 201 and a roughly 360-degree twisted orientation was obtained with the waveform of 202 and the waveform of 203.

Fourteenth Embodiment

FIG. 26 shows examples of driving waveforms in the twelfth and thirteenth embodiments comprising a period in which the driving waveform for generating one of the two metastable states applies a voltage pulse with an absolute value greater than the threshold value in the initial state and applies a voltage pulse group whose absolute value for generating Frederick's transition in the liquid crystal molecules is greater than the threshold value of the element and a period in which the voltage absolute value of the voltage pulse group is reduced gradually or in plural steps and a metastable state with a twist angle of roughly (ϕ-180 degrees) with respect to the twist angle of the liquid crystal in the initial state is generated. In the figure, T_{01} corresponds to the period during which Frederick's transition is generated in the liquid crystal molecules, and T_{02} corresponds to the period during which the voltage absolute value is reduced. Also, 301 and 302 indicate the cases in which the voltage is reduced continuously and in steps, respectively. By applying this to the aforementioned liquid crystal display device, a metastable state with a uniform orientation was obtained.

By means of the methods described in the twelfth to the fourteenth embodiments, the liquid crystal display goes to a uniform orientation state when the backlight or other illumination means is switched ON or when operation begins and the subsequent write scanning starts smoothly.

Fifteenth Embodiment

FIG. 27 shows the voltage waveforms applied to scanning electrodes C_1 - C_4, C_{2n-1} and C_{2n} when the scanning electrodes are divided up into two blocks each comprising a number of n odd-numbered rows and n even-numbered rows and each is line-sequentially scanned; i.e., they are scanned in the order C_1, C_3, C_5, ..., C_{2n-1}, C_2, C_4, C_6, ..., C_{2n}, in the time-shared addressing of a display element comprising a total number of 2n (n is an integer) scanning electrodes (C_1, C_2, ..., C_{2n}) as shown in FIG. 28 and their timing. In the figure, t_l is the selection period for scanning electrode C_1, and t_{11} is the nonselection period. Immediately after t_1, the selection period for C_3 is set, immediately after which the selection period for C_5 (not shown) is set, and the selection and scanning of the odd-numbered rows is finished in T_{01}. In the following period of T_{02}, the even-numbered rows are similarly selected and scanned such that one screen of information is written during T_0 (= T_{01} + T_{02}). By applying the method described above to the voltage drive waveforms of each of the above embodiments, the apparent scanning period could be shorted by one half, and flicker in display due to screen scanning could be reduced. Also, in this embodiment, we showed an example in which scanning was performed by skipping every other scanning electrode so that one screen of information was written by scanning the screen twice, but the number of scanning electrodes skipped and the number of blocks they are divided up into can be set as desired. When a number of n scanning electrodes is divided up into blocks each having k scanning electrodes and one screen is formed by scanning n/k times, where the time (selection period) required to select one row is Ts, then the following relationship should be satisfied

$$k/(Ts \cdot n) \geq fc$$

fc: critical frequency (Hz) at which an observer becomes aware of flicker

Sixteenth Embodiment

Since the liquid crystal display element of the invention uses two metastable states in display, a written display is retained as a memory condition over a fixed period (Tm below). Therefore, the continuous scanning of all scanning electrodes is performed in cycles defined by

$$fref > 1/Tm \text{ (Hz)}$$

and upon completion of one continuous scanning, the display of an entire screen can be maintained by line-sequentially applying a selection waveform in the period

$$1/fref - Ts \cdot n \text{ (n: all scanning electrodes)}$$

to only the scanning electrodes containing the area where it becomes necessary to rewrite the display information. When we applied the above method using fref = 1.67×10^{-2} to the driving waveforms of each of the above embodiments, except for the period during which scanning of the entire screen was performed in one cycle every 60 seconds, there were no optical fluctuations in areas where display information was not rewritten, and in areas where it became necessary to rewrite display in-

formation (scanning line number ns), display was realized in which overall flicker was reduced because partial scanning was performed at a frequency of 1/ns (Hz).

Effectiveness of the Invention

As described above, by means of the liquid crystal display device of the invention, a high speed multiplex-driven liquid crystal display device can be realized with a high contrast ratio and wide effective viewing angle by using switching between two metastable states which can be selected as desired by the applied waveform. Also, since the selected state is retained as a memory state over a period (approximately 10 seconds) at least greater than the scanning time for one screen, the invention can be applied to a high precision display with a large number of scanning lines and driven by simple matrix driving. The invention is applicable to not only direct-view liquid crystal display devices but also to various types of light valves, spatial light modulators, the print head of electronic photographic systems, etc.

Claims

1. A liquid crystal display device having a chiral nematic liquid crystal sandwiched between a pair of transparent electrode substrates (3, 4, 5) equipped with liquid crystal alignment layers (2), where said chiral nematic liquid crystal has a twisted structure of twist angle ϕ in its initial state and has two metastable states different from said initial state as relaxation states after the voltage that brings about a Frederick's transition in said initial state is applied, wherein a voltage applied to bring about the Frederick's transition is a voltage pulse greater than the threshold value in the initial state (V_0) and the two metastable states (Vth_1, Vth_2) and a voltage applied after that to select one of the two metastable states is a voltage pulse selected using the critical value (Vth_1, Vth_2) that generates one of the two metastable states as a reference.

2. A liquid crystal display device having a chiral nematic liquid crystal sandwiched between a pair of transparent electrode substrates equipped with liquid crystal alignment layers, where said chiral nematic liquid crystal has a twisted structure of twist angle ϕ in its initial state and has two metastable states different from said initial state as relaxation states after the voltage that brings about a Frederick's transition in said initial state is applied, wherein a voltage applied to bring about the Frederick's transition is a voltage pulse greater than the threshold value in the initial state and the two metastable states, a voltage applied to select one of the two metastable states is a voltage pulse selected using the critical value that generates one of the two metastable states as a reference, and a voltage applied during a period the selected metastable state is to be maintained is a voltage pulse lower than the threshold value in the two metastable states.

3. The liquid crystal device of claim 1 or 2 wherein the angles (θ_1, θ_2) formed by the director vectors at the interfaces between the liquid crystal and each of the liquid crystal alignment layers, with the respective surface of the pair of transparent electrode substrates in the initial state have opposite signs.

4. The liquid crystal display device of claim 1, 2 or 3 wherein of the twist angles of the liquid crystal molecules in the two metastable states, one is ϕ-180 degrees and the other is ϕ + 180 degrees.

5. The liquid crystal display device of claims 3 and 4 wherein the device has plural critical values and the metastable state having a twist angle of ϕ + 180 degrees is selected when the absolute value of the voltage pulse applied to select one of the metastable states is below the critical value of the lowest absolute value.

6. The liquid crystal display device of claims 3 and 4 wherein the device has plural critical values and the metastable state having twist a angle of ϕ-180 degrees is selected when the absolute value of the voltage pulse applied to select one of the metastable states is a value between the critical value of the lowest absolute value and the critical value of the next lowest absolute value.

7. The liquid crystal display device of any one of the preceding claims 1 wherein a scanning electrode group and a signal electrode group are disposed on the pair of transparent electrode substrates, respectively, and the picture elements comprising those respective groups are driven by time-shared addressing.

8. The liquid crystal display device of any one of the preceding claims wherein the voltage pulse to bring about the Frederick's transition is applied in a first period, the voltage pulse to select one of the two metastable states is applied in a subsequent second period, and the voltage pulse to maintain a selected one of

the metastable states is applied during a third period.

9. The liquid crystal display device of claim 8 wherein the twist angle of the liquid crystal molecules in a metastable state is $\phi + 180$ degrees when the absolute value of the voltage pulse in the second period is between zero and the critical value.

10. The liquid crystal display device of claims 7 and 8 wherein the selection period in time-shared addressing is the first period and second period and the nonselection period is the third period.

11. The liquid crystal display device of claims 7 and 8 wherein the selection period in time-shared addressing is the second period and the nonselection period is the third period and the first period.

12. The liquid crystal device of claims 7 and 8 wherein all picture elements have a first period and a second period before undergoing time-shared addressing.

13. The liquid crystal device of claim 12 wherein all picture elements have the same twist angle before undergoing time-shared addressing, namely ϕ-180 degrees or $\phi + 180$ degrees.

14. The liquid crystal device of claim 12 wherein all picture elements have a first period and a second period simultaneously.

15. The liquid crystal device of claim 12 wherein all picture elements have a first period and a second period sequentially every plural number of scanning electrodes.

16. The liquid crystal device of claim 12 wherein all picture elements have plural first periods and second periods.

17. The liquid crystal device of claim 7 and 8 wherein in the scanning electrode group, an integer number n of scanning electrodes is divided up into blocks each block comprising an integer number k ($k \leq n$) of scanning electrodes and each block is line-sequentially scanned such that each screen is time-shared n/k times.

18. The liquid crystal device of claims 7 and 8 wherein only the scanning electrodes including picture elements that must be rewritten after the scanning electrodes are scanned in one cycle are provided with a first period and a second period and are driven by time-shared addressing.

19. Driving method for a liquid crystal display device that sandwiches chiral nematic liquid crystal between a pair of transparent electrode substrates equipped with liquid crystal alignment layers, where said chiral nematic liquid crystal has a twisted structure in its initial state and has two metastable states different from said initial state as relaxation states after the voltage that brings about a Frederick's transition in said initial state is applied, wherein after the Frederick's transition is brought about, one of the metastable states is generated by applying the voltage pulse whose absolute value is selected using the critical value that generates one of the metastable states as a reference, after which the selected metastable state is maintained by applying the voltage pulse below the threshold value in the two metastable states.

20. The driving method for a liquid crystal display device of claim 19 wherein a scanning electrode group and a signal electrode group are disposed on the pair of transparent electrode substrates, respectively, and the picture elements comprising those respective groups are driven by time-shared addressing.

21. The driving method for a liquid crystal display device of claim 20 wherein Frederick's transition is brought about and one of the metastable states is selected in the selection period in time-shared addressing and the selected metastable state is maintained in the nonselection period.

22. The driving method for a liquid crystal display device of claim 20 wherein one of the metastable states is selected in the selection period in time-shared addressing and the selected metastable state is maintained and Frederick's transition is brought about in the nonselection period.

23. The driving method for a liquid crystal display device of claim 20 wherein Frederick's transition is brought about for all picture elements and one of the metastable states is selected before time-shared addressing.

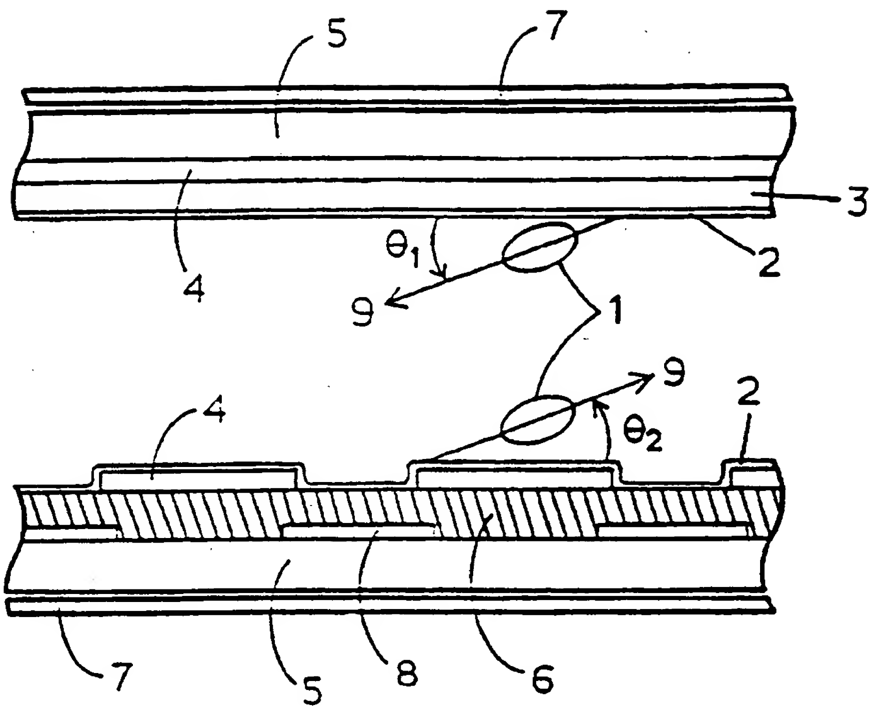


FIG. 1

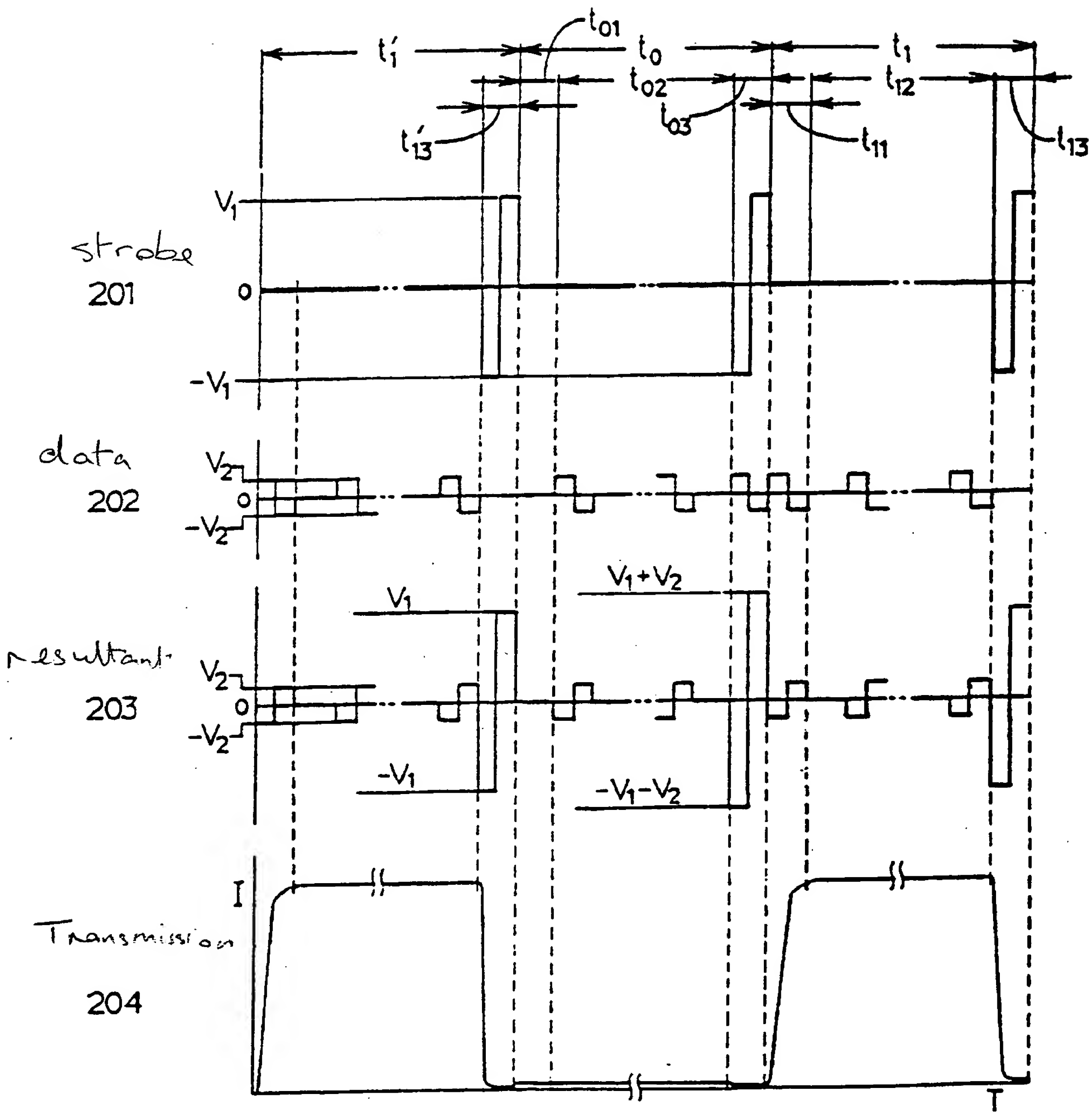

t_1'
t_{01}
t_0
t_1
t_{02}
t_{12}
t_{13}'
t_{03}
t_{11}
t_{13}
strobe
201
V_1
0
$-V_1$
data
202
V_2
0
$-V_2$
resultant
203
V_1
V_1+V_2
V_2
0
$-V_2$
$-V_1$
$-V_1-V_2$
Transmission
204
I
T

FIG. 2

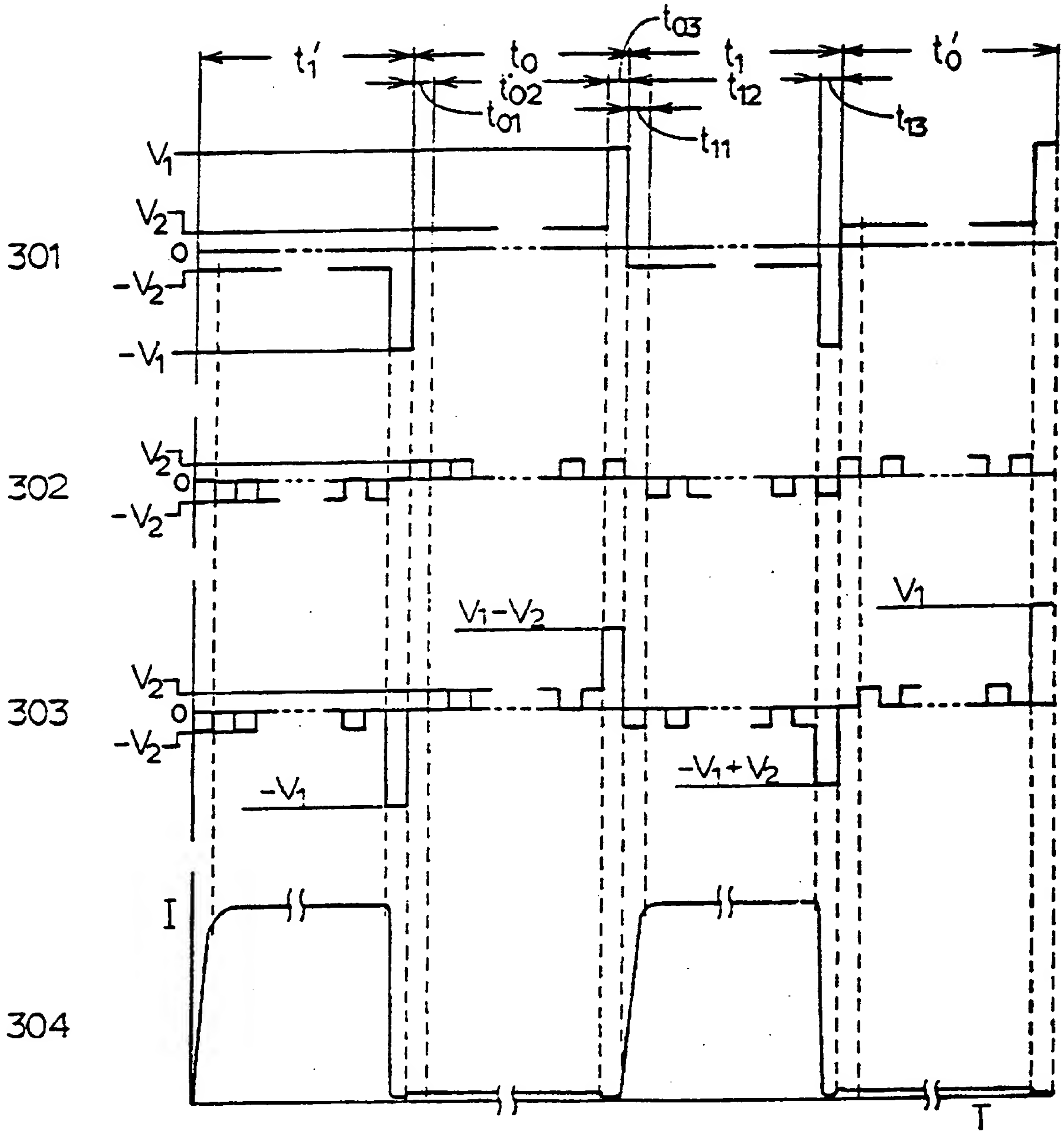

t1'
t0
t03
t1
t0'
t02
t12
t01
t11
t13
V1
V2
0
-V2
-V1
301
302
V1-V2
V1
303
-V1
-V1+V2
I
304
T

FIG. 3

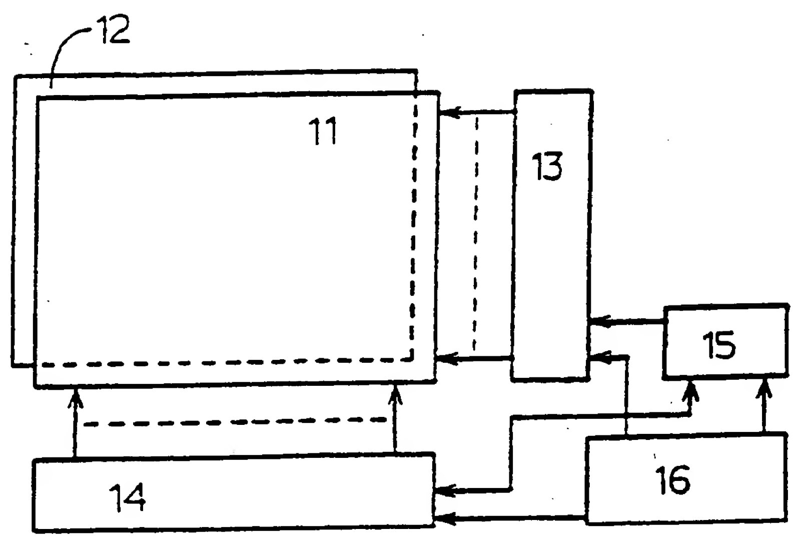

12
11
13
15
14
16

FIG. 4

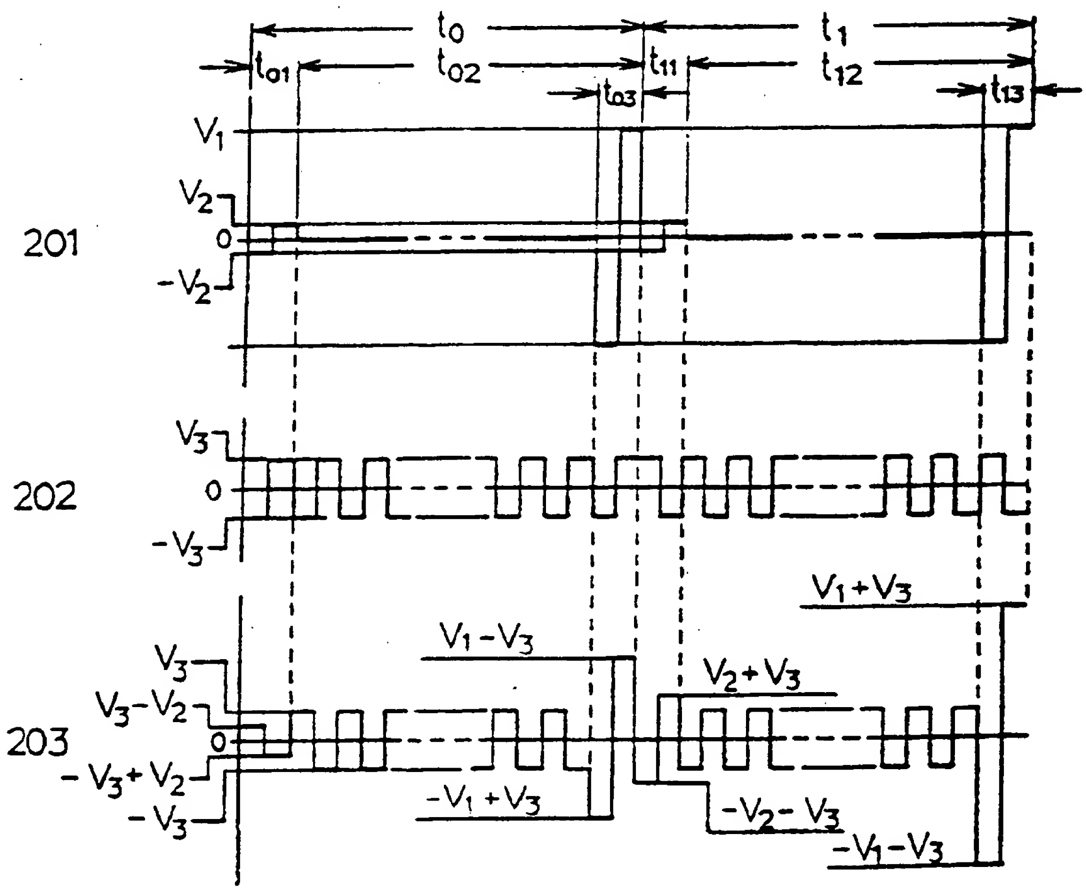

t0
t1
t01
t02
t11
t12
t03
t13
V1
V2
0
-V2
201
V3
0
-V3
202
V1+V3
V1-V3
V2+V3
V3
V3-V2
0
-V3+V2
-V3
203
-V1+V3
-V2-V3
-V1-V3

FIG. 5

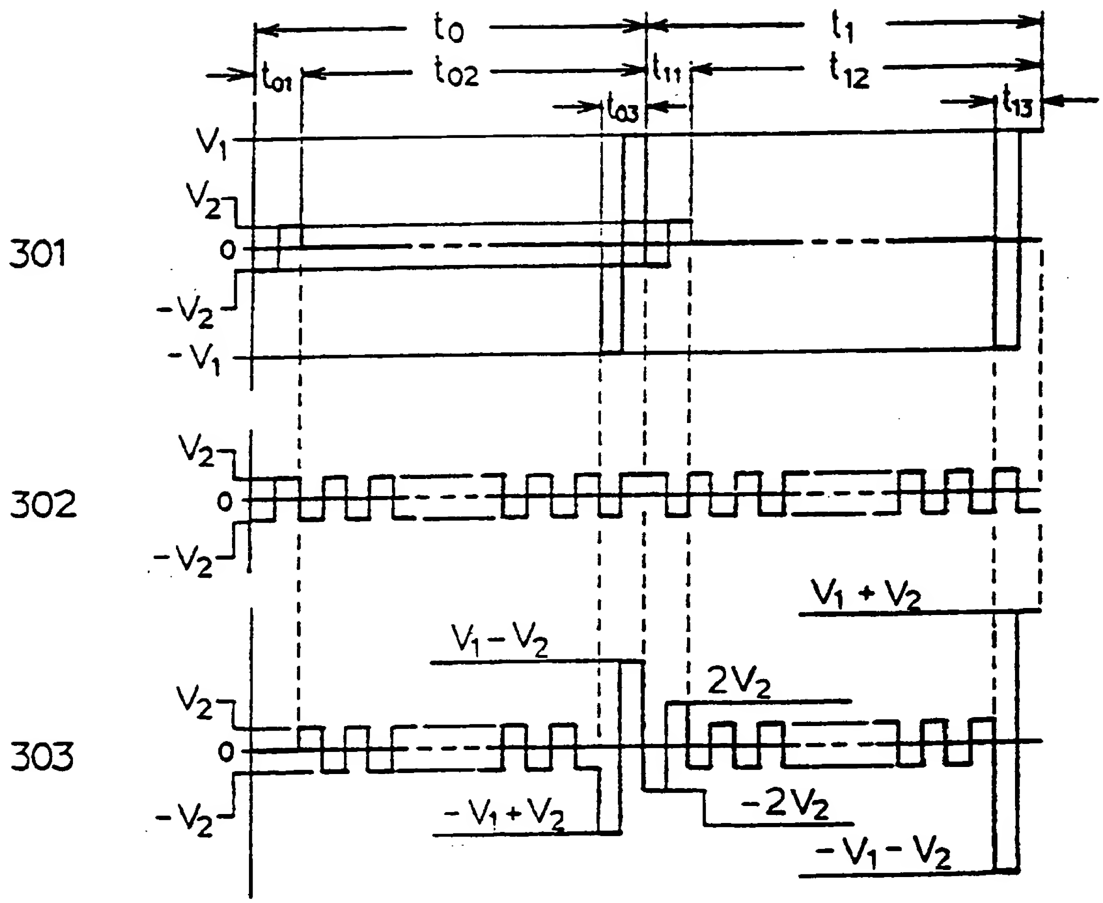

t0
t1
t01
t02
t11
t12
t03
t13
V1
V2
0
-V2
-V1
301
302
303
V1 + V2
V1 - V2
2V2
-V1 + V2
-2V2
-V1 - V2

FIG. 6

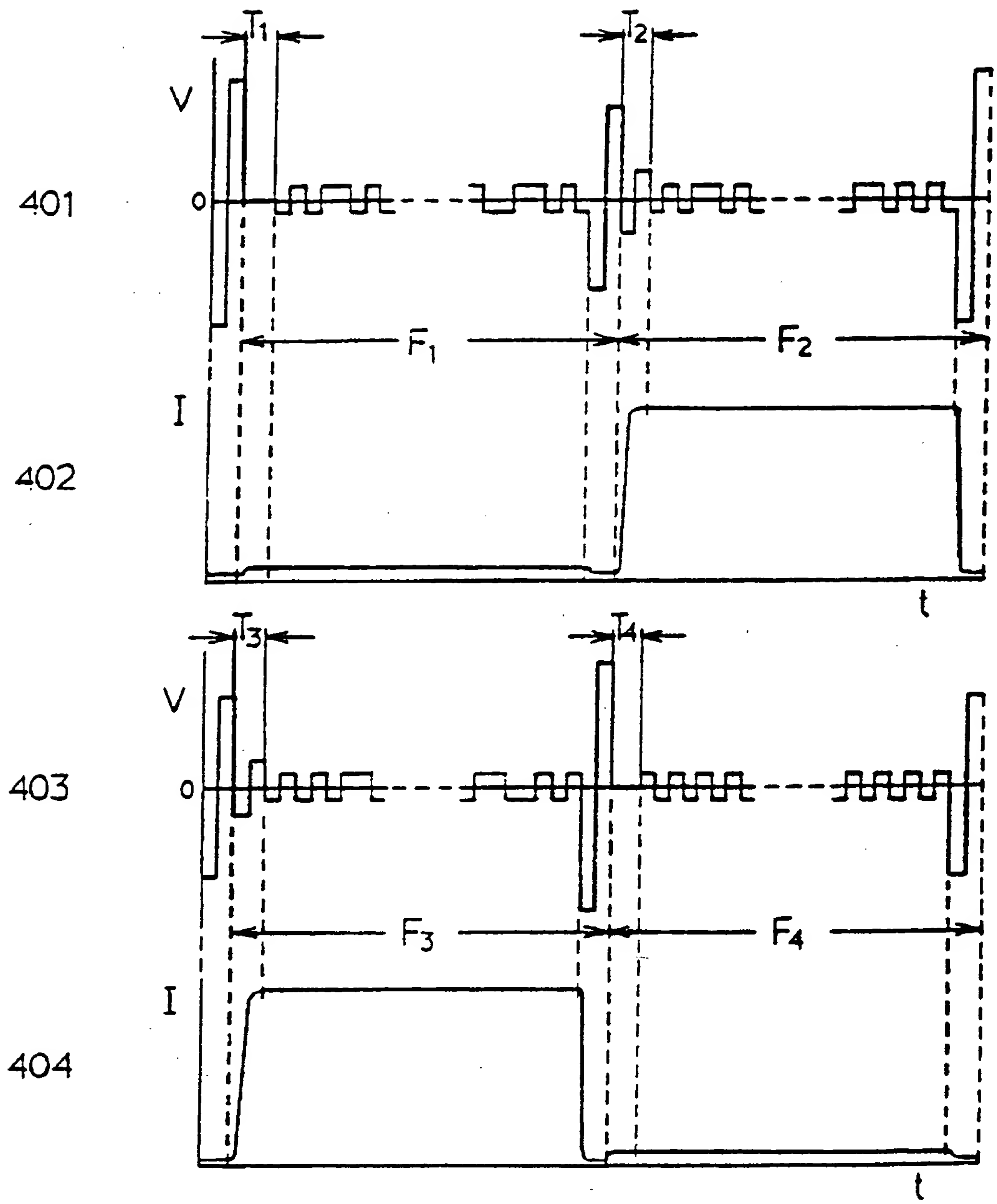


FIG. 7

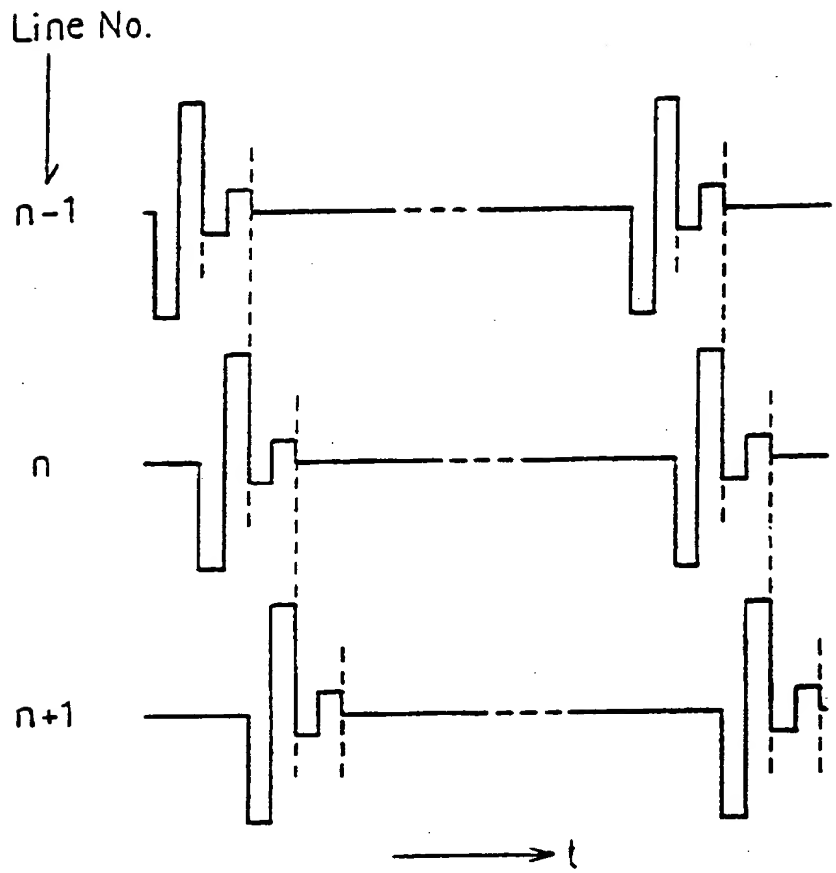


FIG. 8

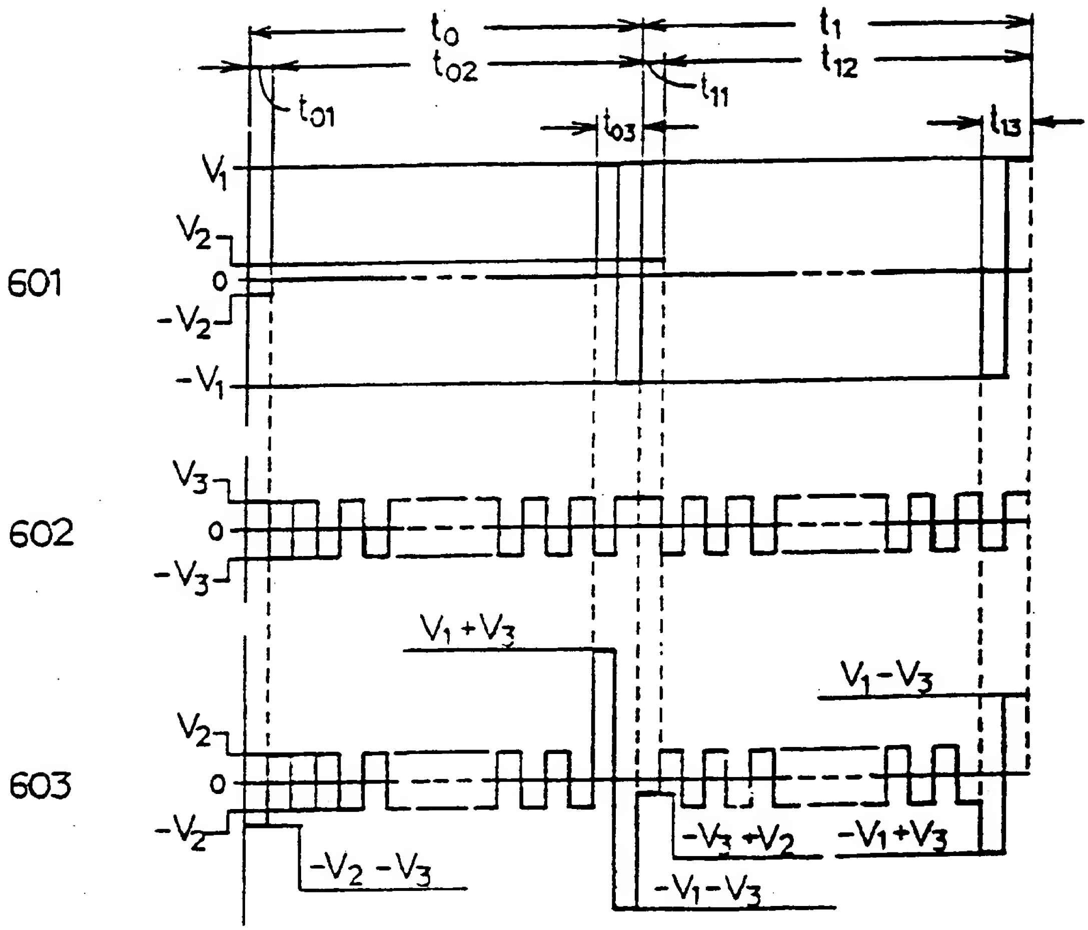
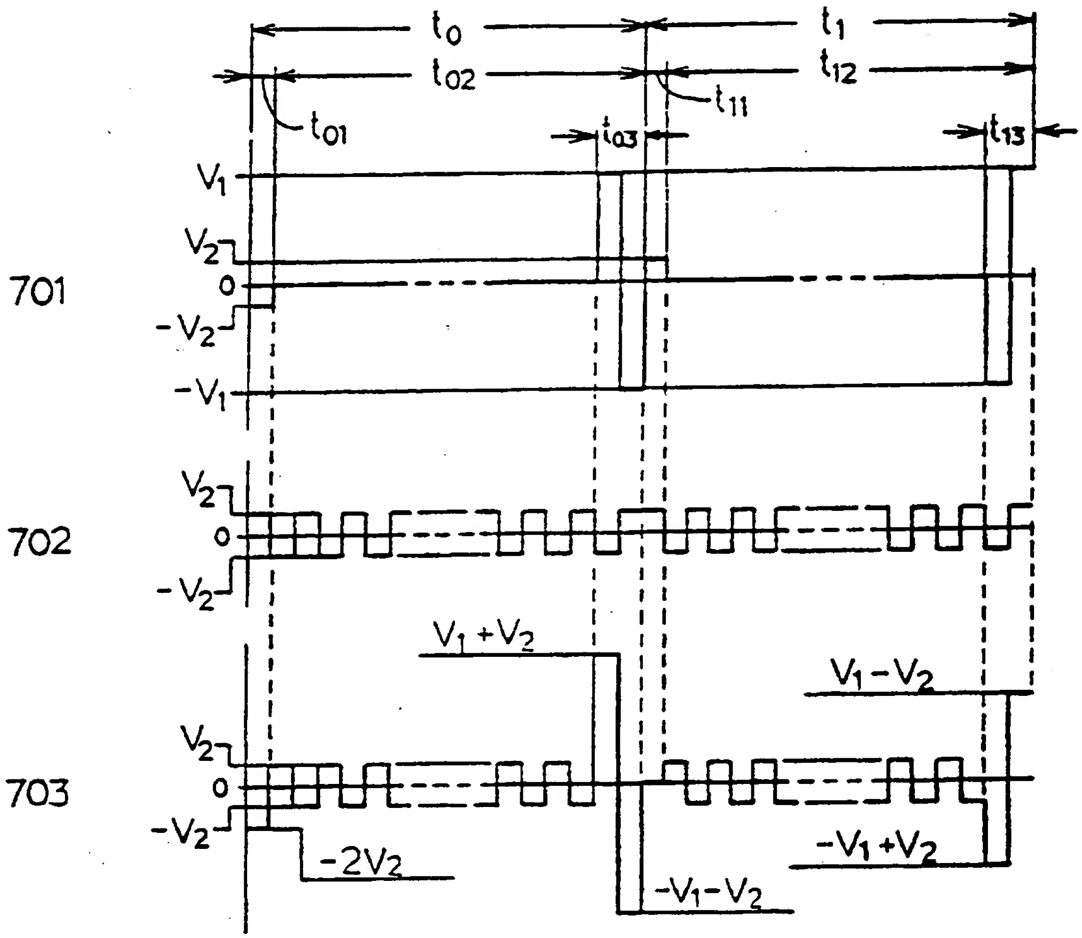

t_0
t_1
t_{02}
t_{12}
t_{01}
t_{11}
t_{03}
t_{13}
V_1
V_2
601
0
$-V_2$
$-V_1$
V_3
602
0
$-V_3$
V_1+V_3
V_1-V_3
V_2
603
0
$-V_2$
$-V_3+V_2$
$-V_1+V_3$
$-V_2-V_3$
$-V_1-V_3$

FIG. 9



t0
t1
t02
t12
t01
t11
t03
t13
V1
V2
0
-V2
-V1
701
702
703
V1 +V2
V1 - V2
-2V2
-V1 - V2
-V1 +V2

FIG. 10

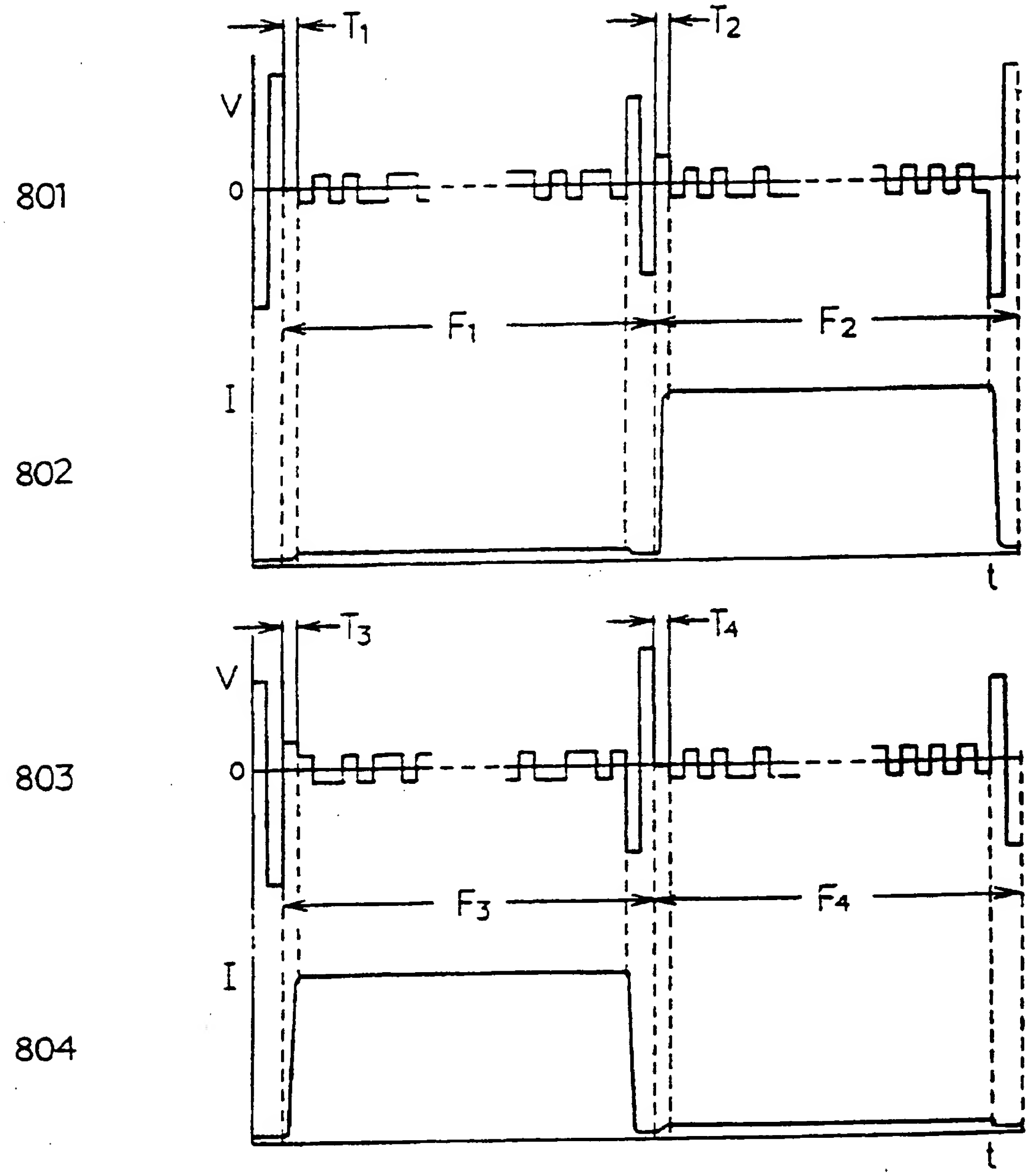


FIG. 11

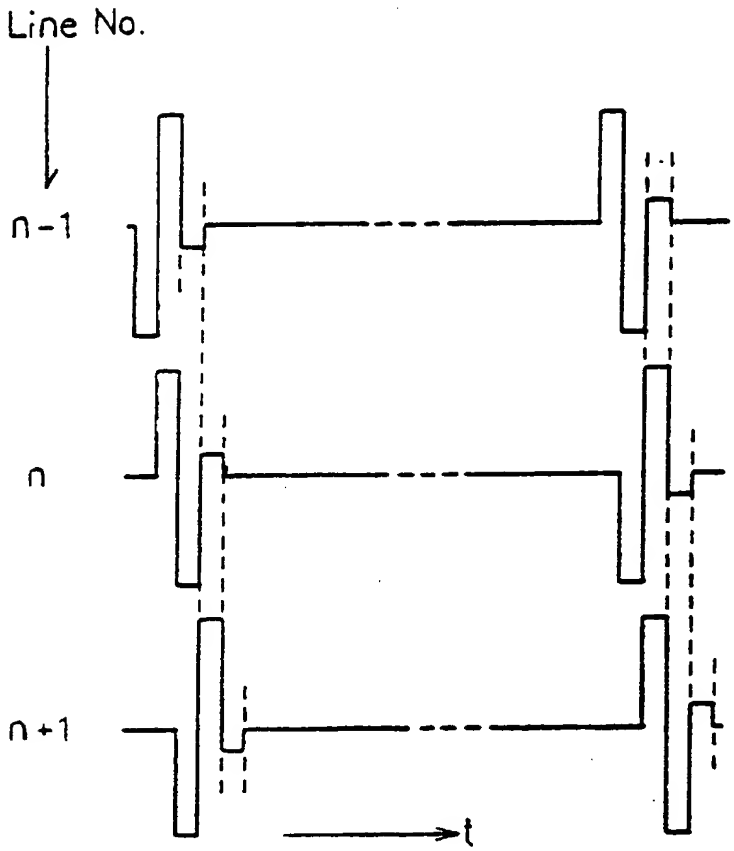


FIG. 12

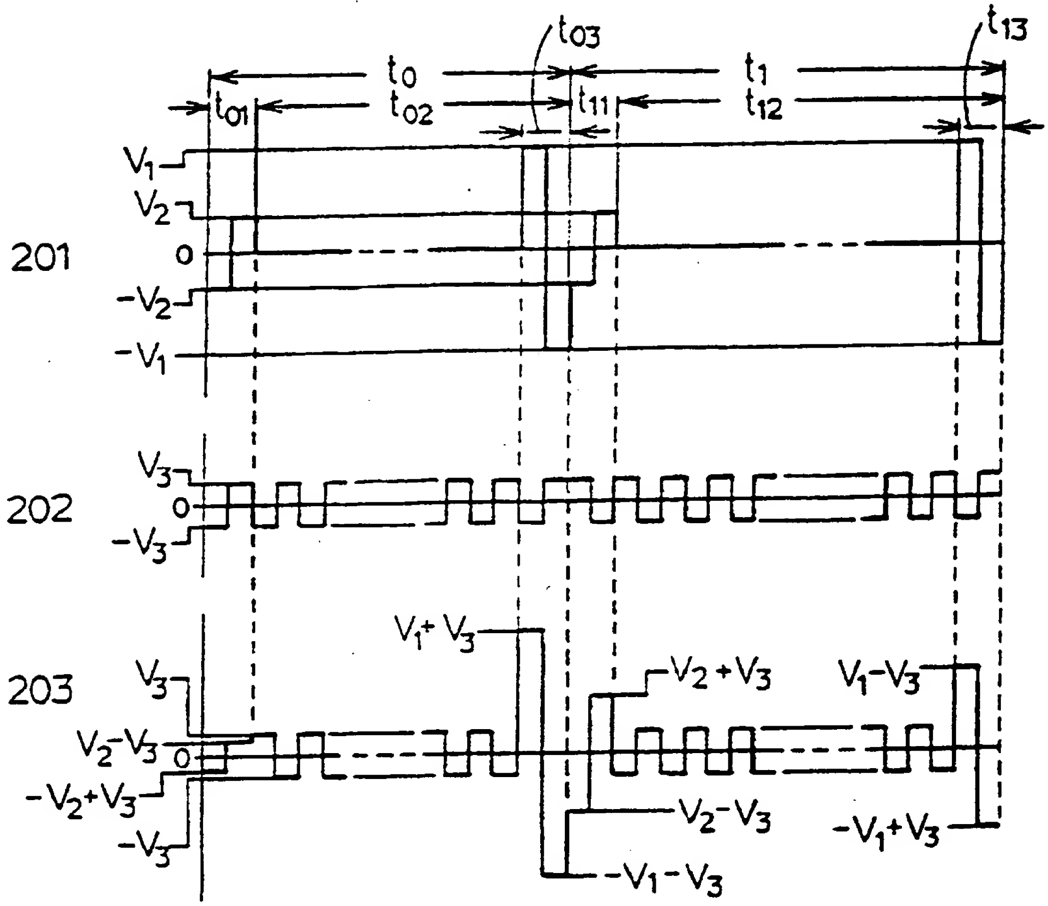
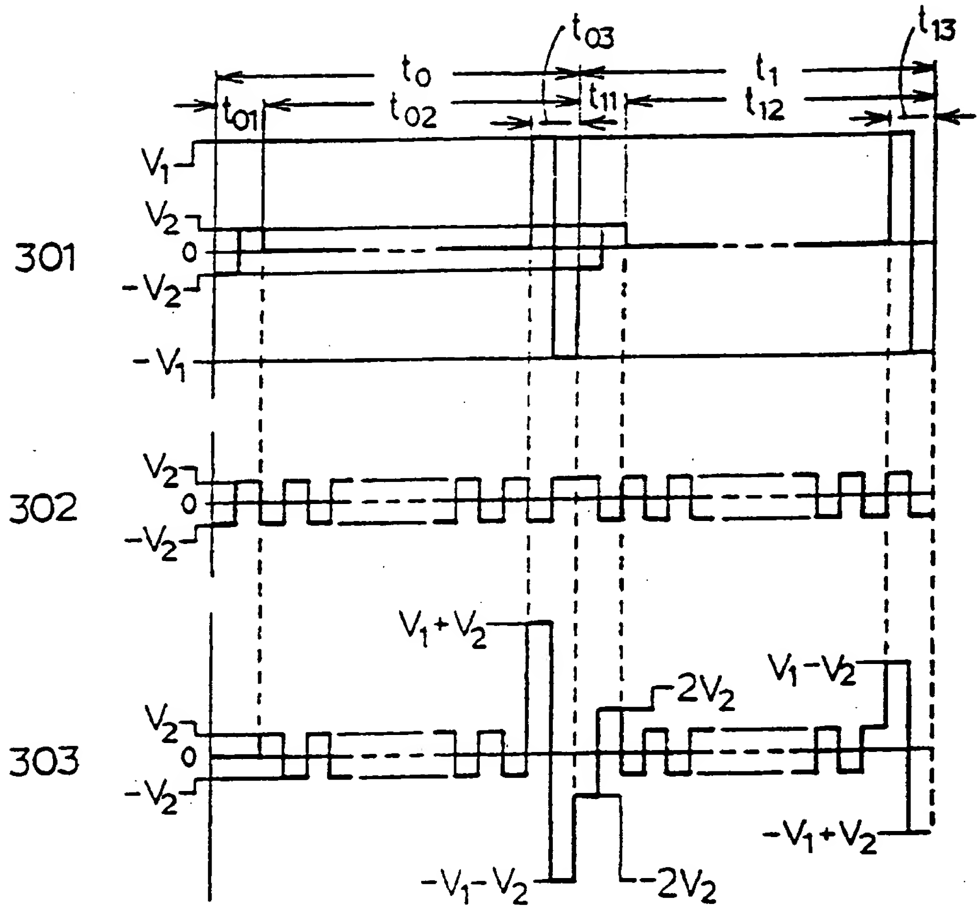

t_{03}
t_{13}
t_0
t_1
t_{01}
t_{02}
t_{11}
t_{12}
V_1
V_2
201
0
$-V_2$
$-V_1$
V_3
202
0
$-V_3$
V_1+V_3
203
V_3
$-V_2+V_3$
V_1-V_3
V_2-V_3
0
$-V_2+V_3$
V_2-V_3
$-V_1+V_3$
$-V_3$
$-V_1-V_3$

FIG. 13



t_{03}
t_{13}
t_0
t_1
t_{01}
t_{02}
t_{11}
t_{12}
V_1
V_2
0
$-V_2$
$-V_1$
301
302
303
V_1+V_2
$-2V_2$
V_1-V_2
$-V_1+V_2$
$-V_1-V_2$
$-2V_2$

FIG. 14

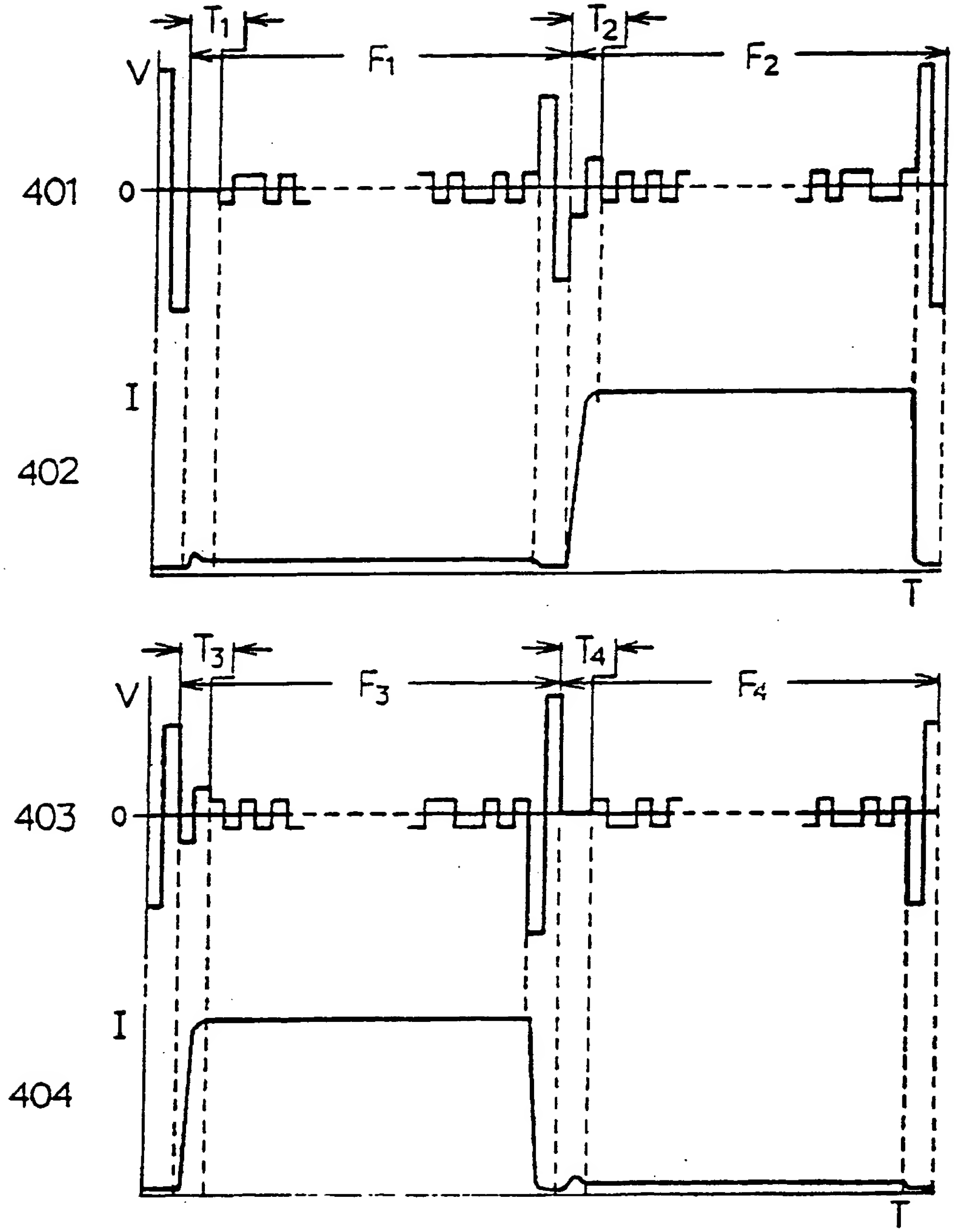


FIG. 15

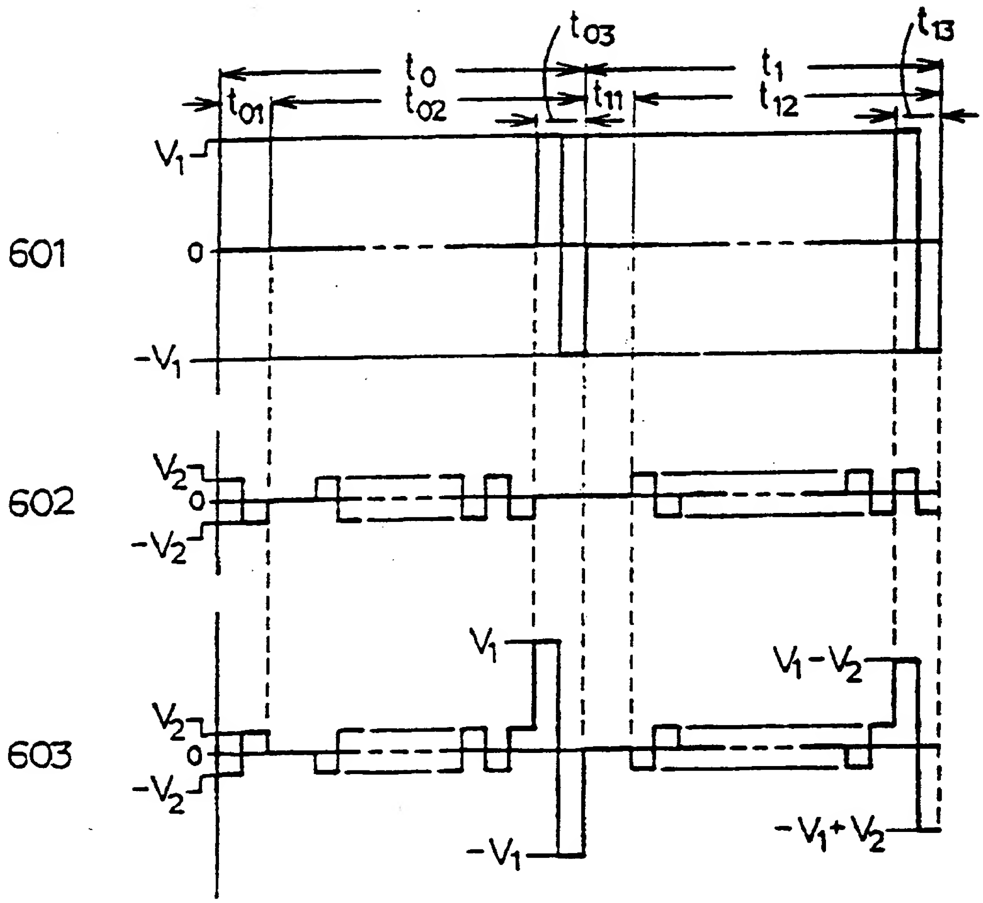

t03
t13
t0
t1
t01
t02
t11
t12
V1
0
-V1
601
V2
0
-V2
602
V1
V1-V2
V2
0
-V2
603
-V1
-V1+V2

FIG. 16

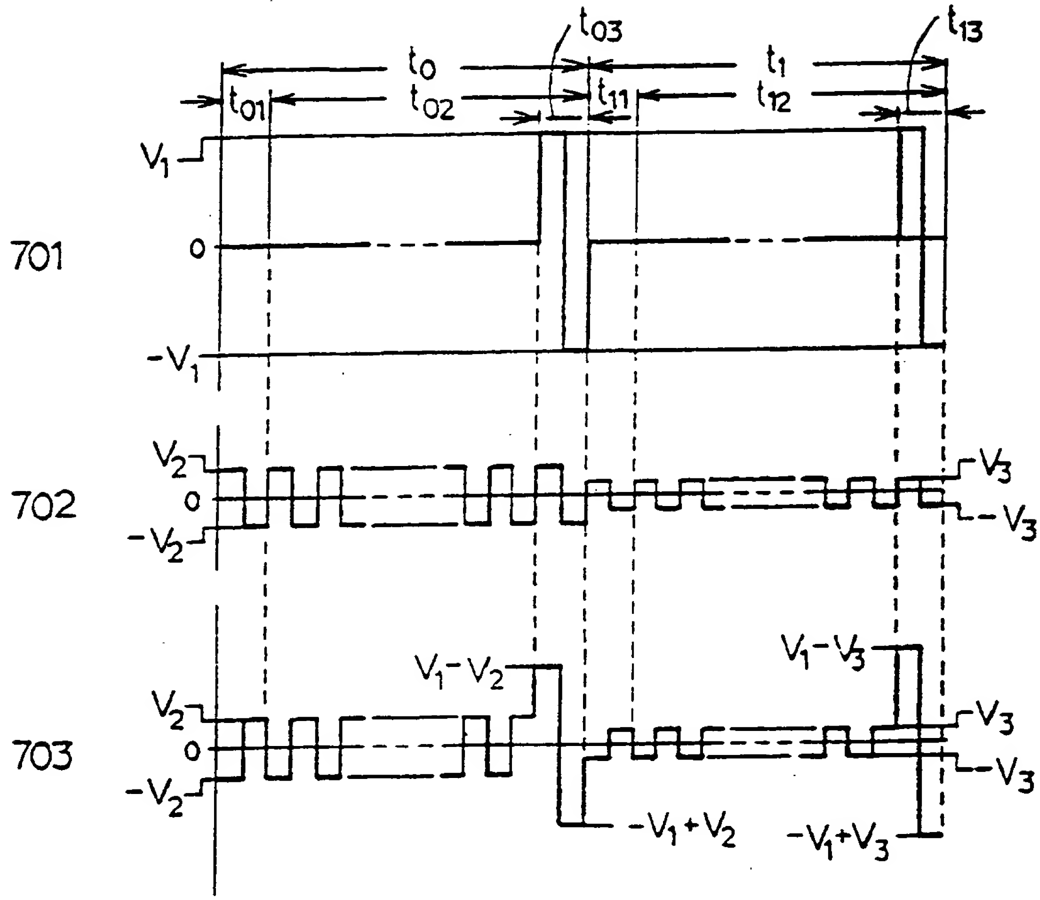

t_0
t_{03}
t_1
t_{13}
t_{01}
t_{02}
t_{11}
t_{12}
V_1
701
0
$-V_1$
V_2
702
0
$-V_2$
V_3
$-V_3$
V_1-V_2
V_1-V_3
V_2
703
0
$-V_2$
V_3
$-V_3$
$-V_1+V_2$
$-V_1+V_3$

FIG. 17

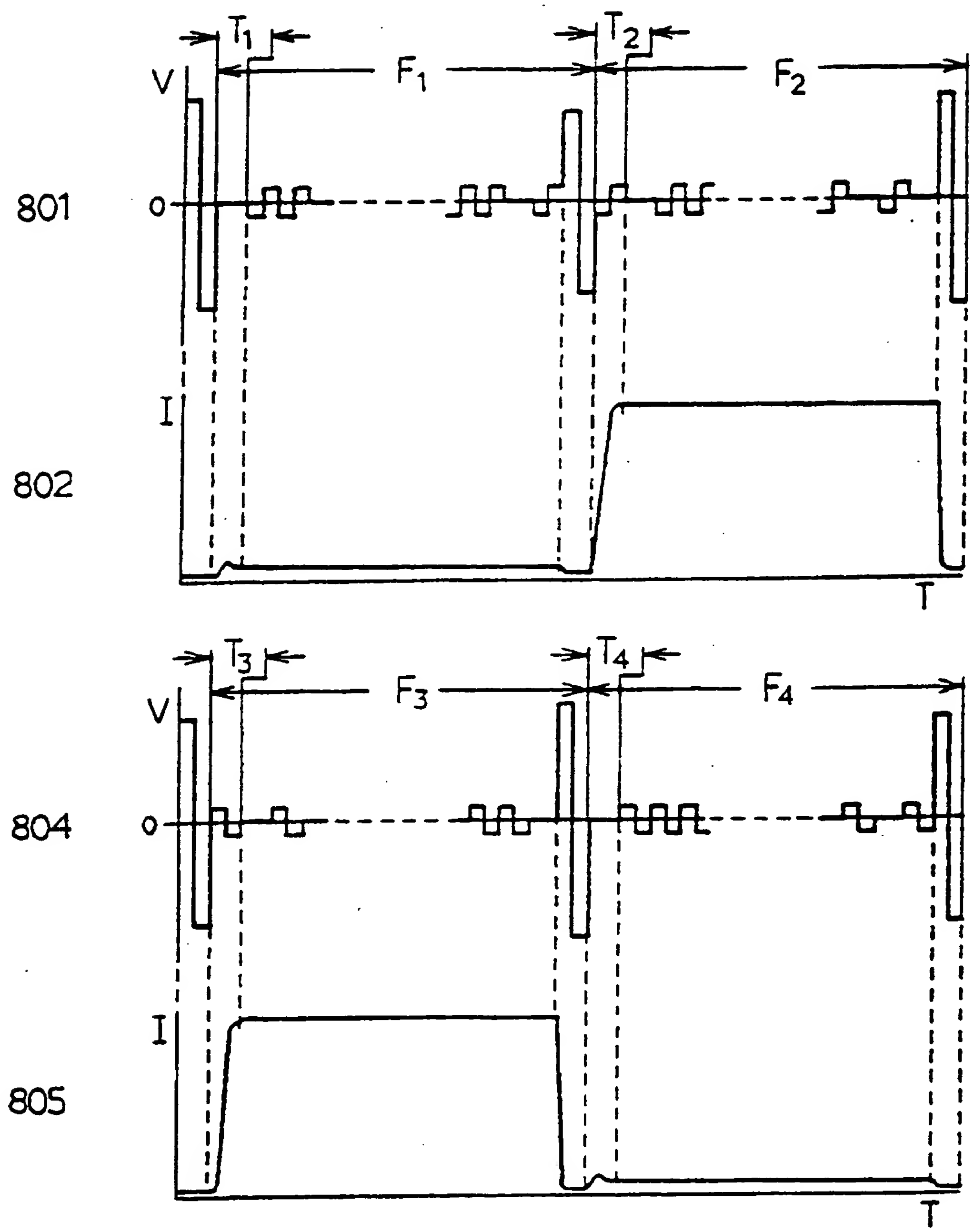


FIG. 18

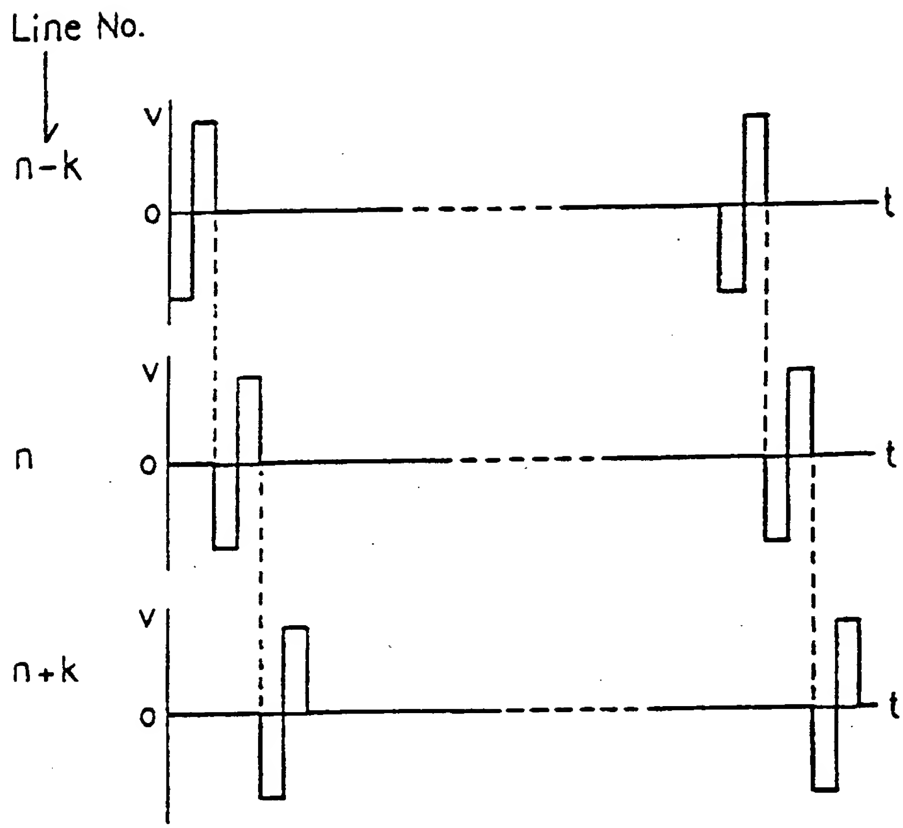


FIG. 19

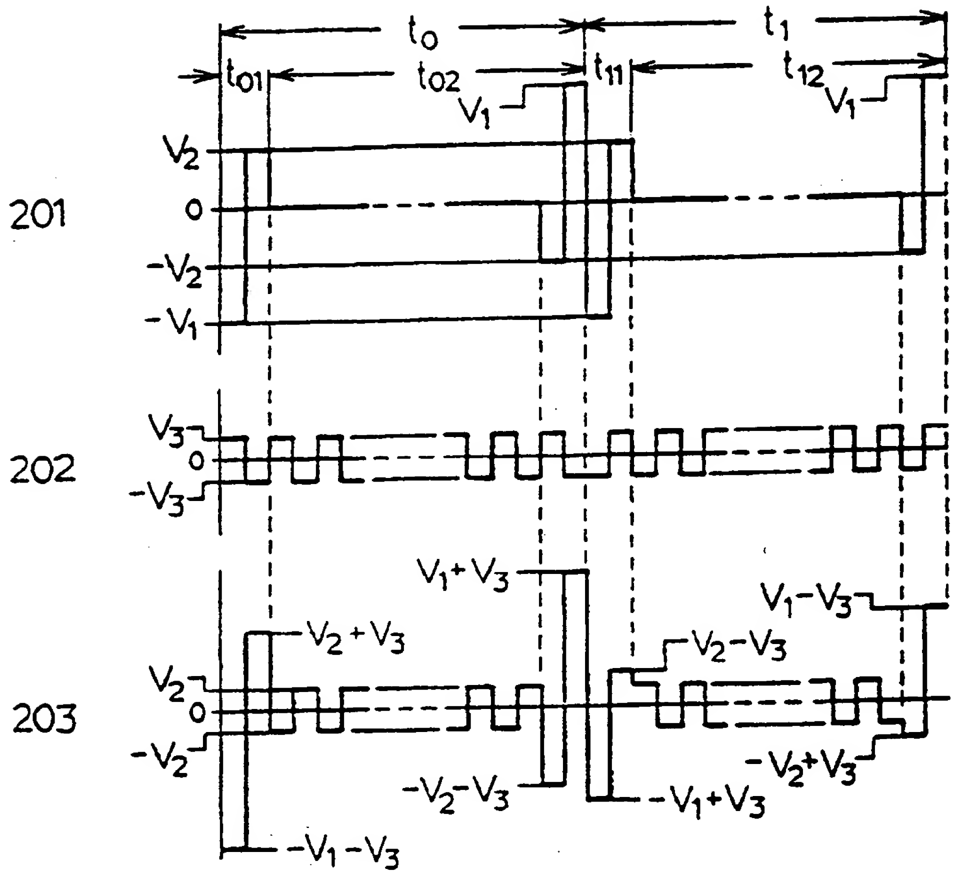

t0
t1
t01
t02
t11
t12
V1
V1
V2
0
-V2
-V1
201
V3
0
-V3
202
V1+V3
V1-V3
V2+V3
V2-V3
V2
0
-V2
203
-V2-V3
-V1+V3
-V2+V3
-V1-V3

FIG. 20

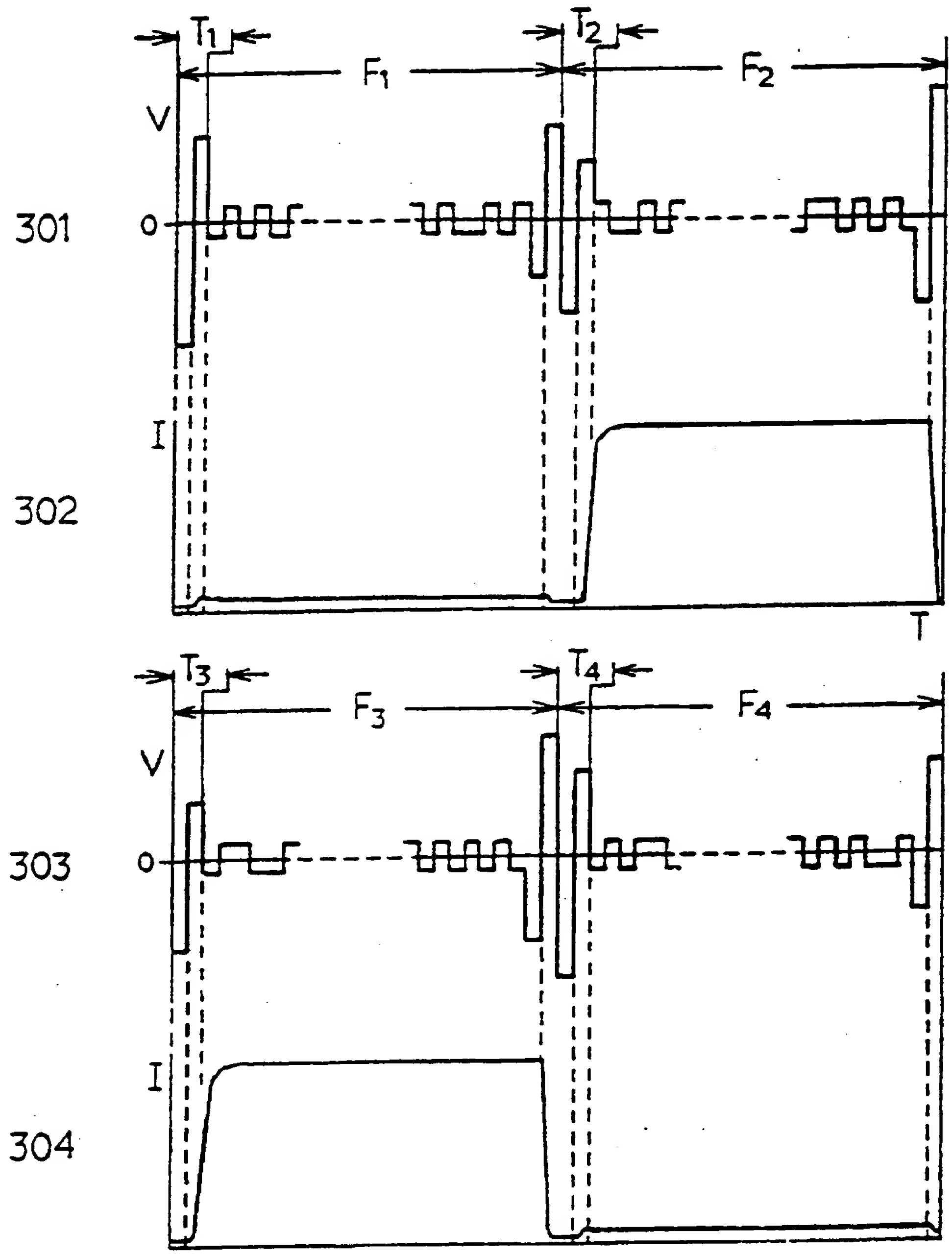


FIG. 21

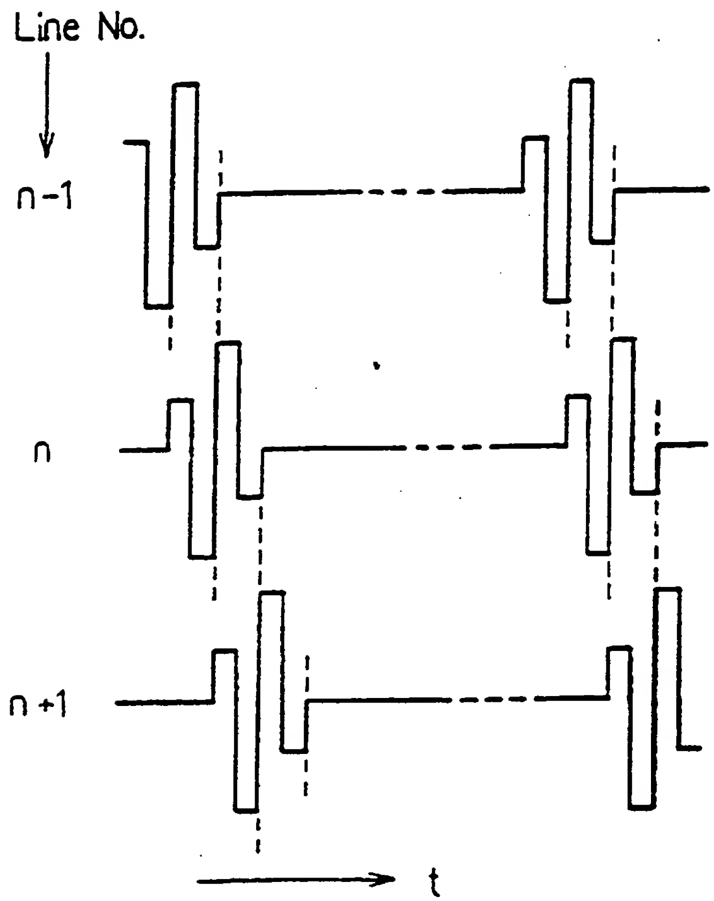


FIG. 22

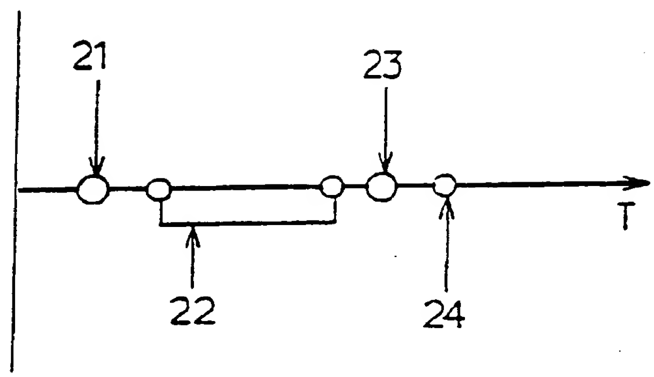


FIG. 23

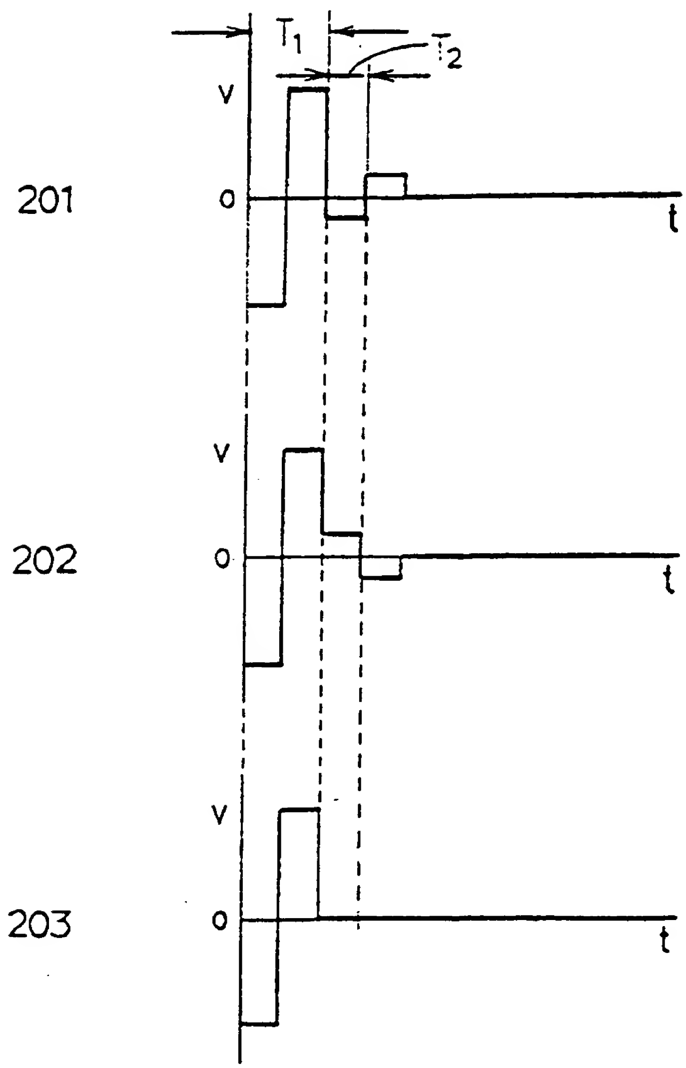


FIG. 24

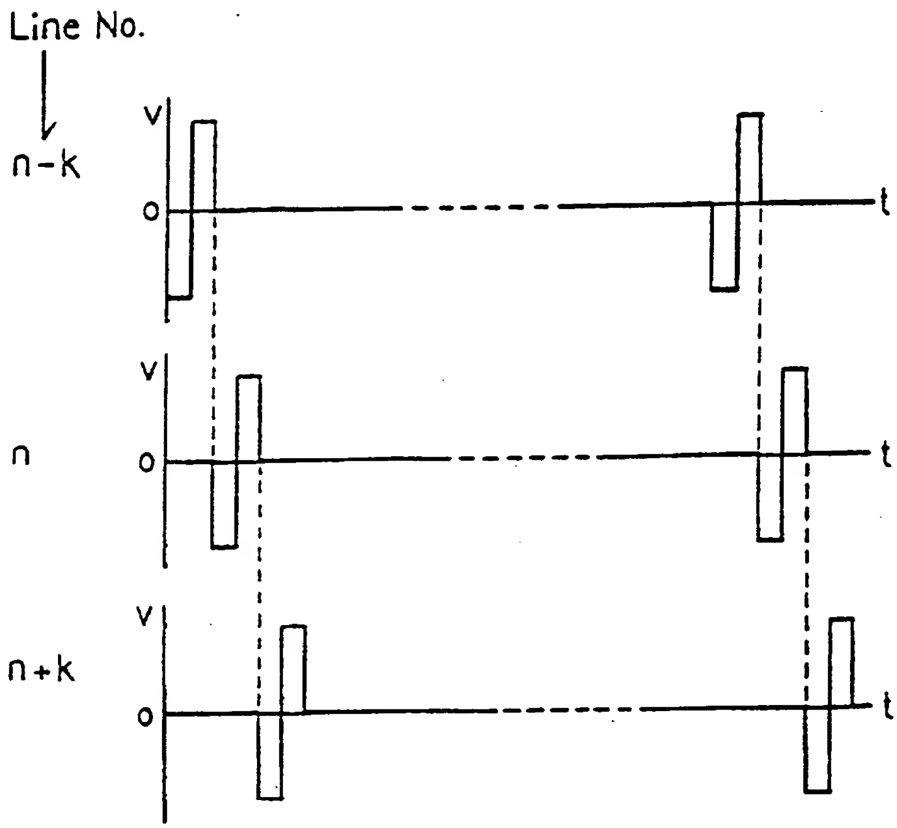


FIG. 25

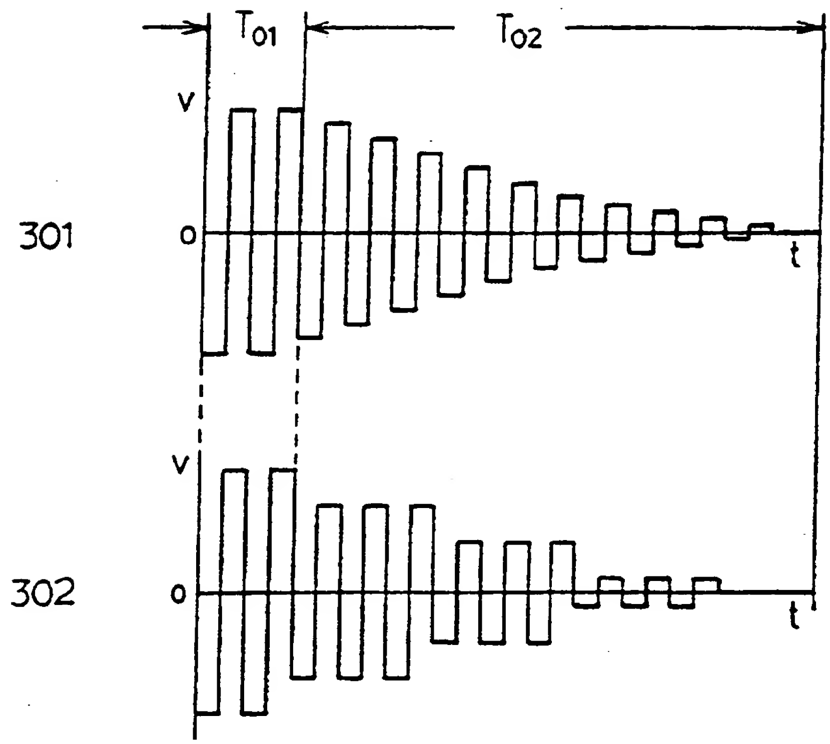


FIG. 26

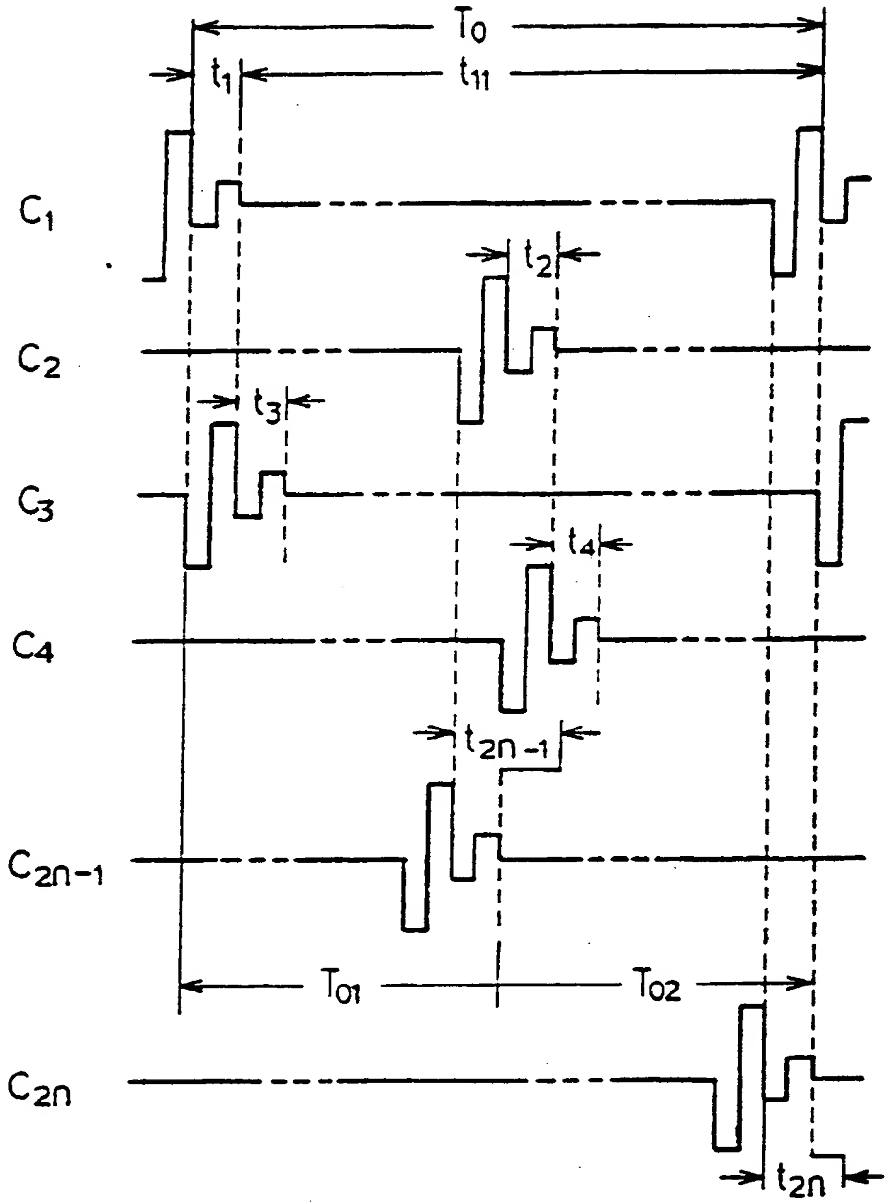


FIG. 27

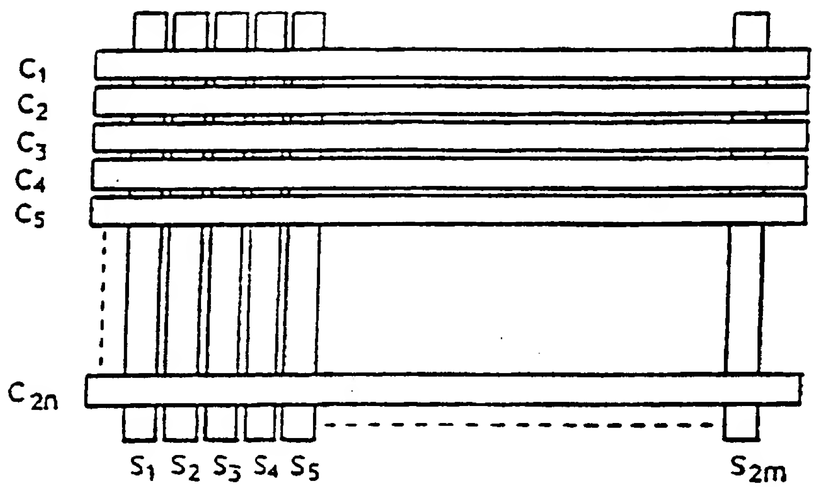


FIG. 28

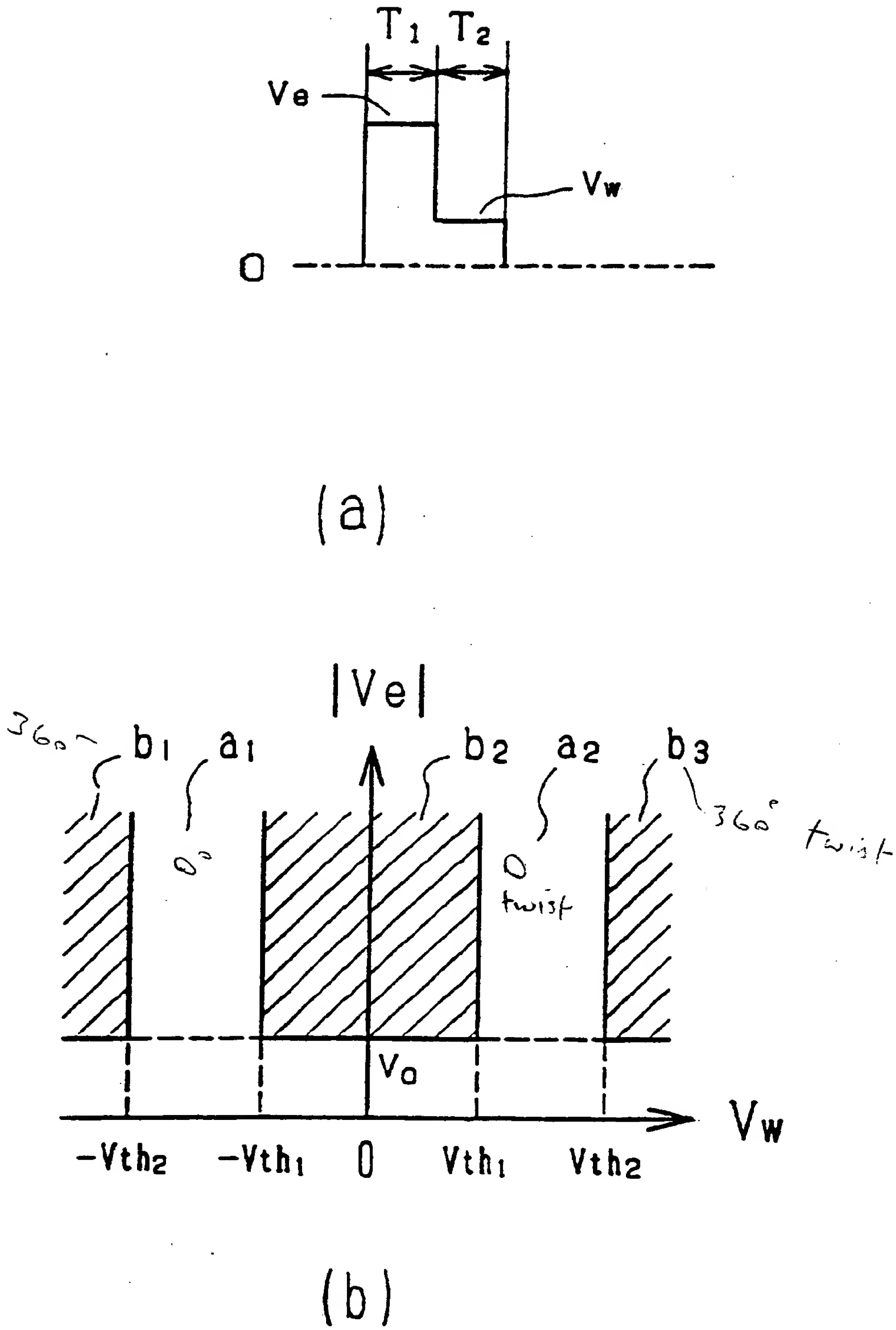

T1
T2
Ve
Vw
0
(a)
|Ve|
360°
b1
a1
b2
a2
b3
0°
0 twist
360° twist
Vo
Vw
-Vth2
-Vth1
0
Vth1
Vth2
(b)

FIG. 29

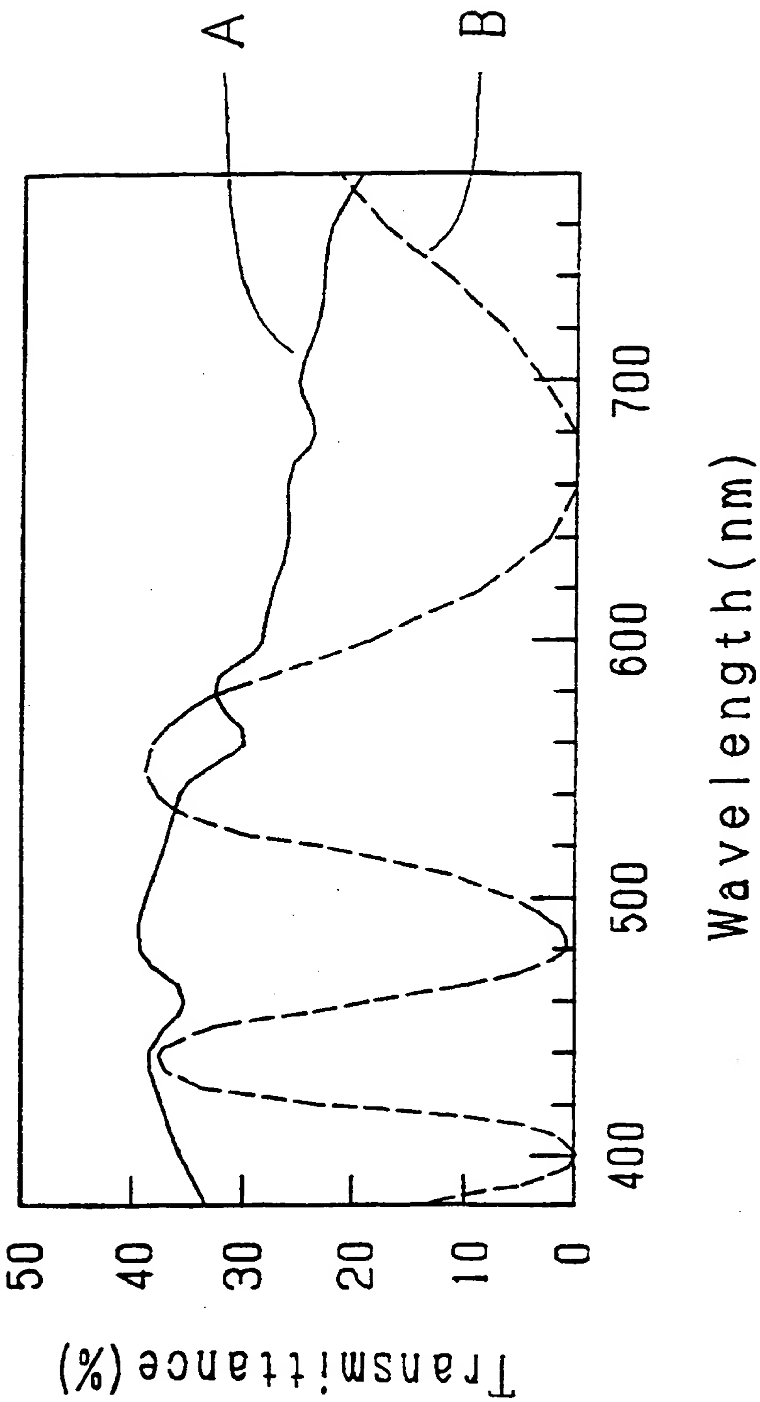

A
B
400
500
600
700
Wavelength (nm)
0
10
20
30
40
50
Transmittance (%)

FIG. 30

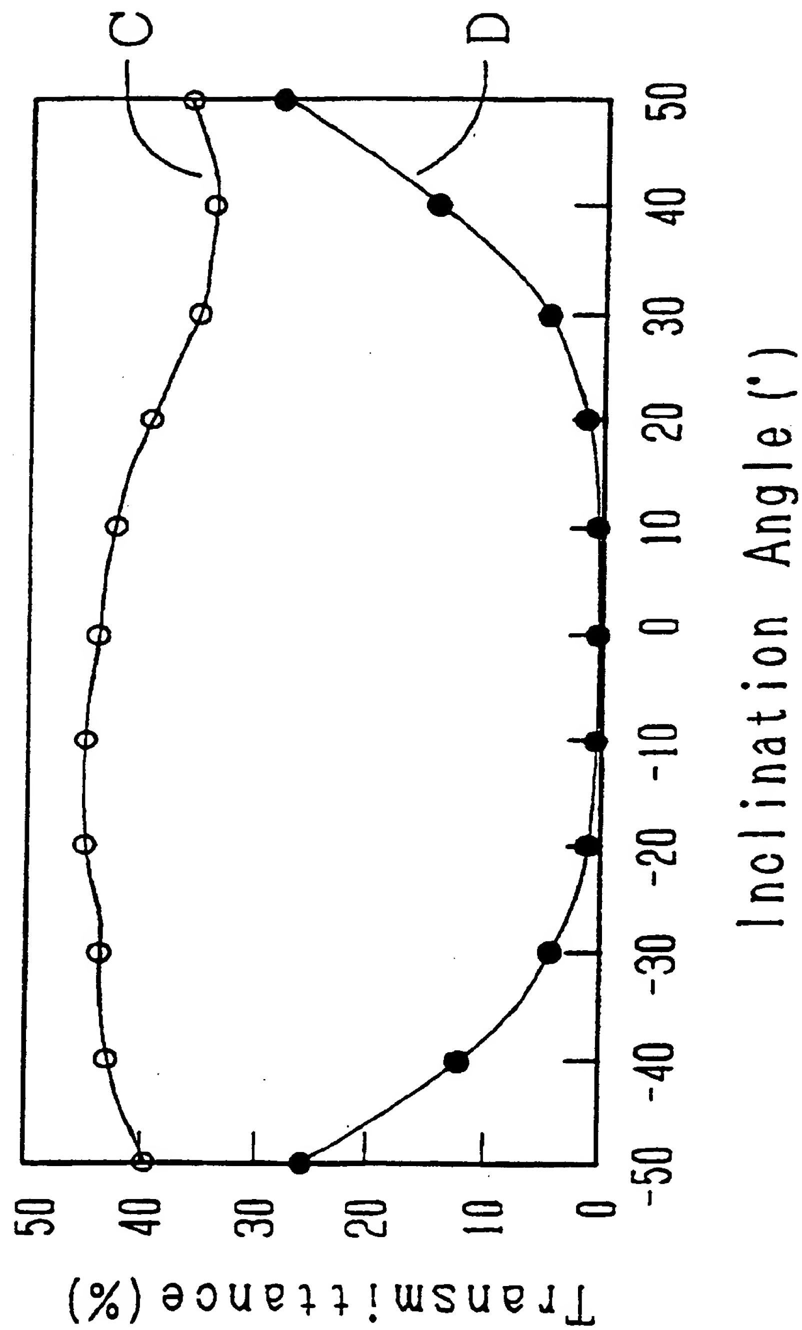

C
D
Transmittance (%)
50
40
30
20
10
0
-50
-40
-30
-20
-10
0
10
20
30
40
50
Inclination Angle (°)

FIG. 31

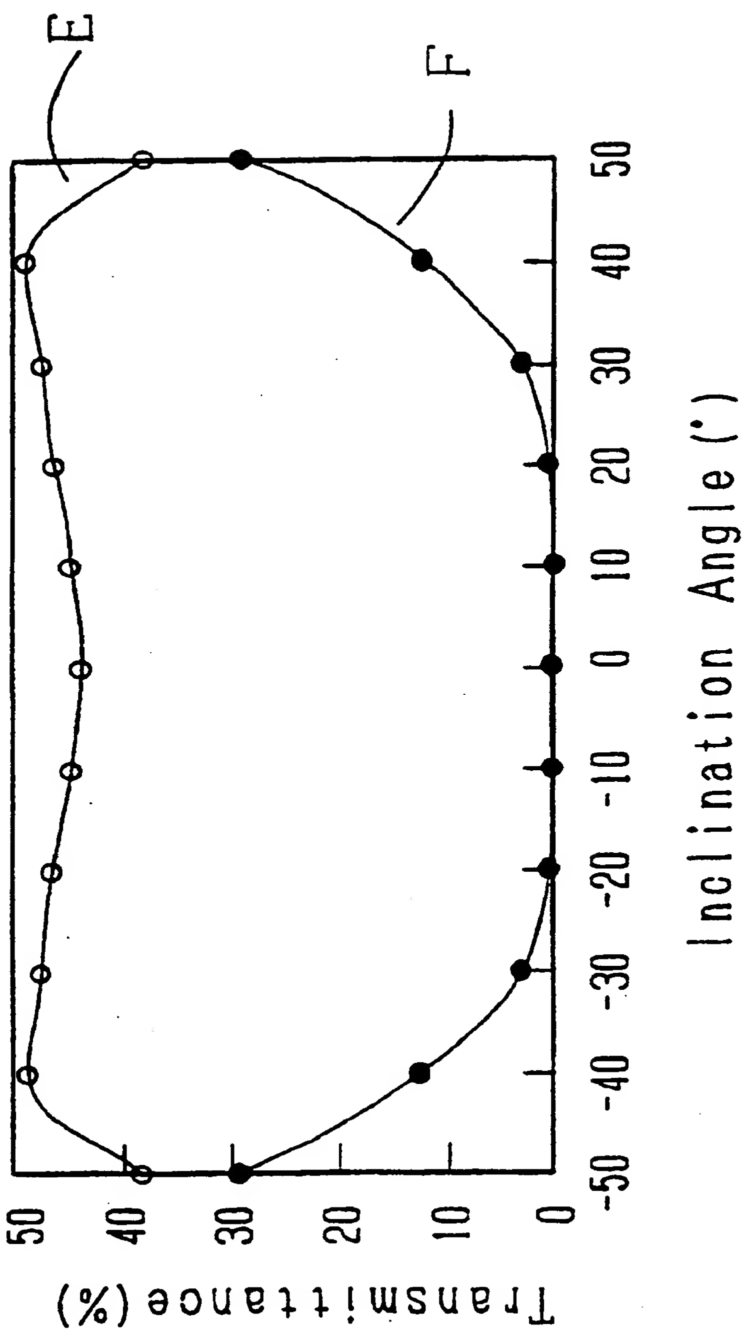

E
F
Transmittance (%)
50
40
30
20
10
0
-50
-40
-30
-20
-10
0
10
20
30
40
50
Inclination Angle (°)

FIG. 32

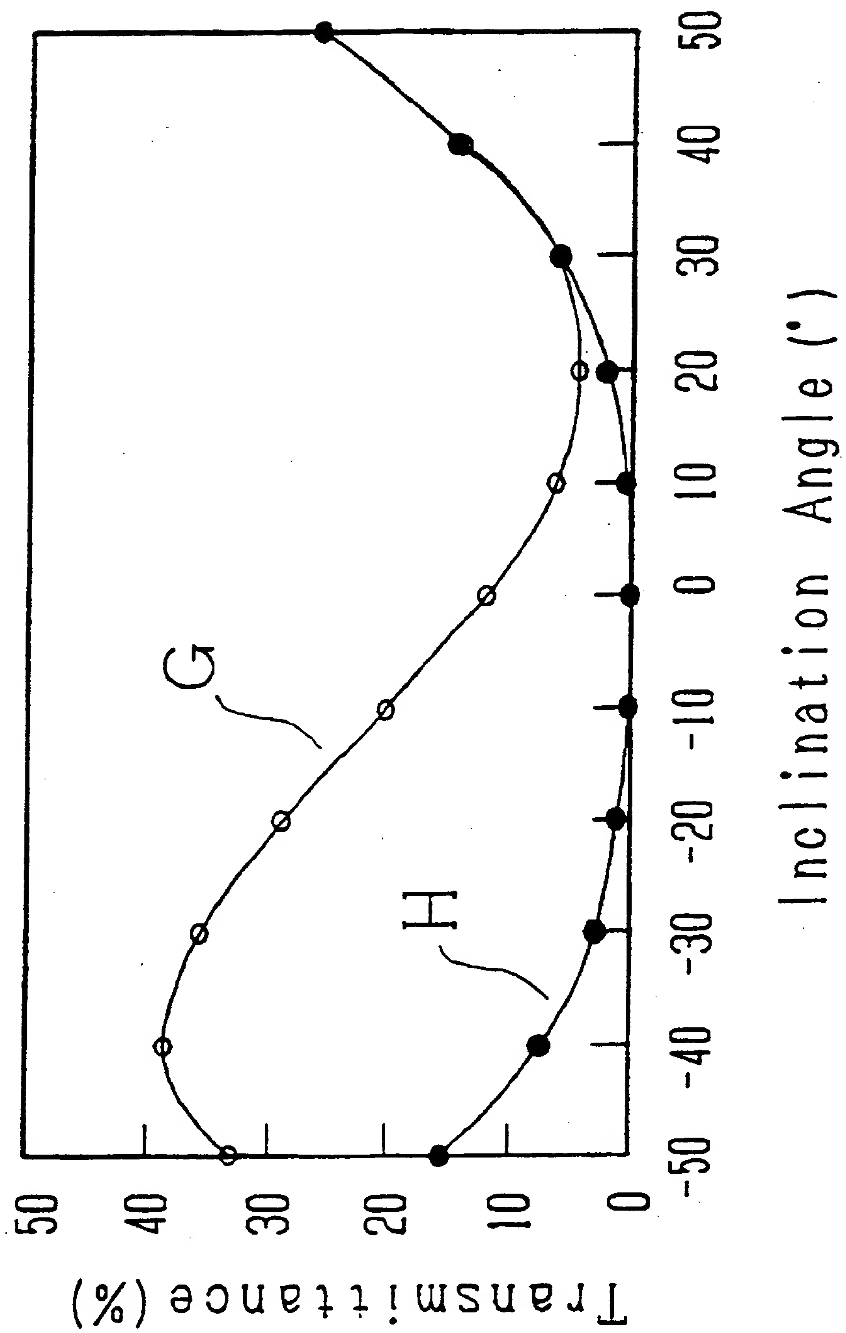

Transmittance (%)
0
10
20
30
40
50
-50
-40
-30
-20
-10
0
10
20
30
40
50
Inclination Angle (°)
G
H

FIG. 33

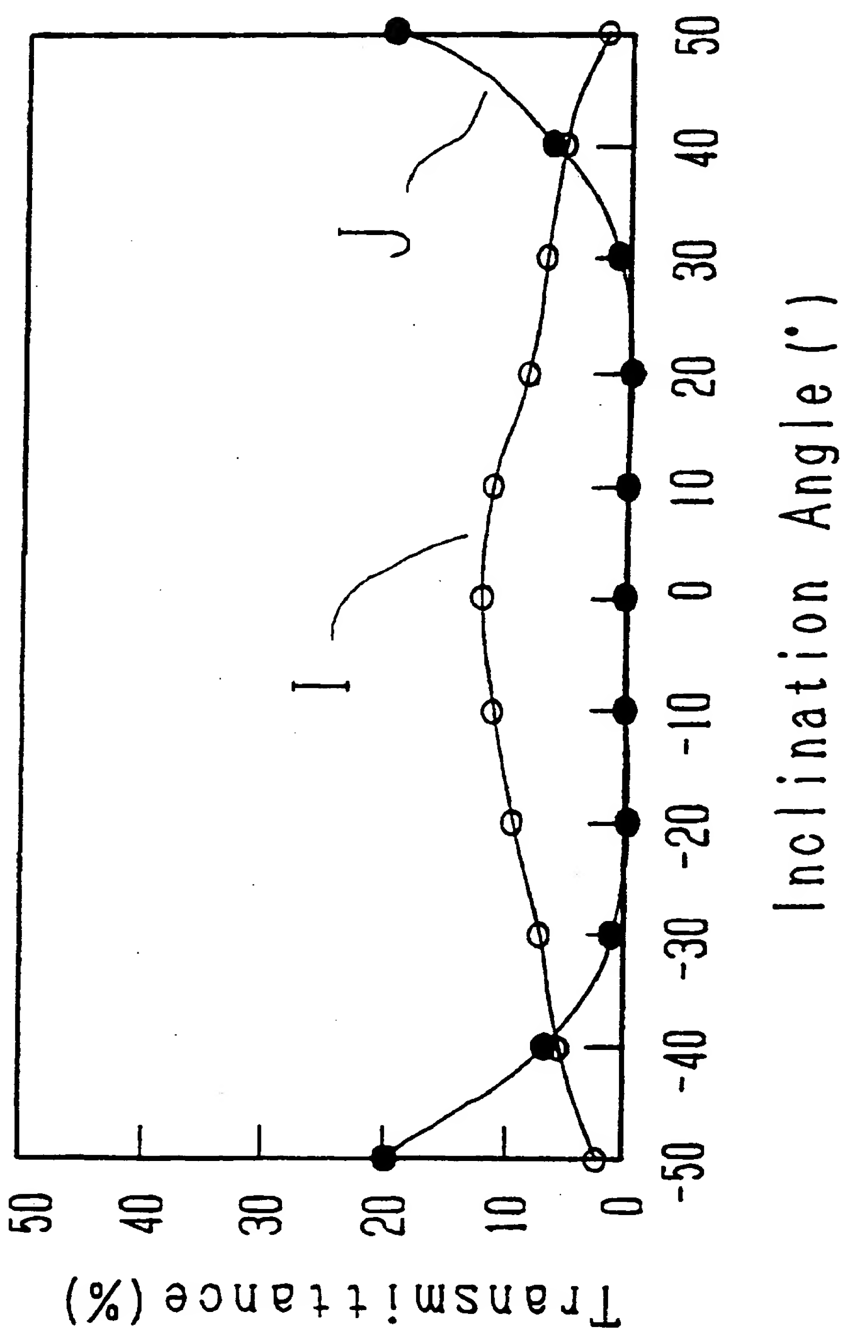

Transmittance (%)
Inclination Angle (°)
I
J
50
40
30
20
10
0
-50
-40
-30
-20
-10
0
10
20
30
40
50

FIG. 34

(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: **0 569 029 A3**

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(21) Application number: **93107467.8**

(22) Date of filing: **07.05.93**

(30) Priority: **07.05.92 JP 114480/92**
02.06.92 JP 141442/92
16.07.92 JP 189437/92
17.08.92 JP 217932/92
07.12.92 JP 326914/92
07.12.92 JP 326915/92

(43) Date of publication of application:
10.11.93 Bulletin 93/45

(84) Designated Contracting States:
DE FR GB

(88) Date of deferred publication of the search report:
12.10.94 Bulletin 94/41

(51) Int. Cl.5: **G09G 3/36, G02F 1/137**

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3-5, Owa 3-chome
Suwa-shi, Nagano-ken 392 (JP)

(74) Representative: **Blumbach Weser Bergen**
Kramer Zwirner Hoffmann Patentanwälte
Bahnhofstrasse 103
D-82166 Gräfelfing (DE)

(54) Liquid crystal display device having two metastable states and its driving method.

(57) A liquid crystal display device containing chiral nematic a liquid crystal having a twisted structure is provided with a period during which a pulse voltage is applied that brings about a Frederick's transition and a period during which a voltage pulse, which is selected using the critical value that generates one of the two metastable states as a reference, is applied, and it displays by switching between the bistable states. Thereby a high speed multiplex-driven liquid crystal display device capable of performimg high precision display while maintaining high contrast and a wide viewing angle is achieved.

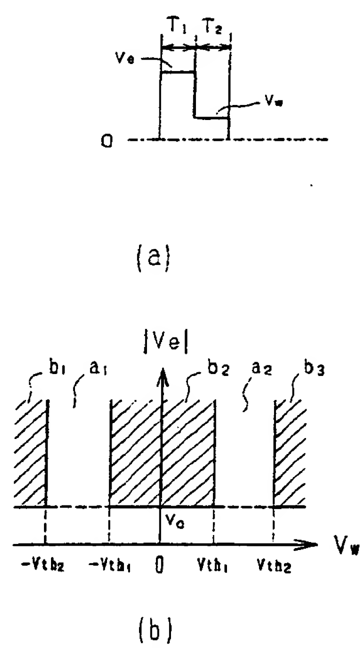

FIG. 29

EP 0 569 029 A3

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 93 10 7467

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.5)
A	EP-A-0 422 904 (SHARP K.K.) * page 3, line 5 - page 5, line 5 * ---	1,2,19	G09G3/36 G02F1/137
A	APPLIED PHYSICS LETTERS, vol.45, no.10, 15 November 1984, NEW YORK US pages 1021 - 1023 SCHEFFER ET AL. 'A new, highly multiplexable liquid crystal display' ---		
A	APPLIED PHYSICS LETTERS, vol.43, no.4, 15 August 1983, NEW YORK US pages 342 - 344 MEYER ET AL. 'Discovery of dc switching of a bistable boundary layer liquid crystal display' ---		
A	GB-A-2 233 106 (CITIZEN WATCH CO. LTD.) ---		
E	EP-A-0 579 247 (SEIKO EPSON CORPORATION) * page 2, line 34 - line 42 * * page 4, line 8 - line 19 * * page 18, line 21 - line 30 * * figure 11 * -----	1	TECHNICAL FIELDS SEARCHED (Int.Cl.5) G09G G02F

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	11 August 1994	Farricella, L

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document